Civil Engineering Practical Notes A-Z

Second Edition

Vincent T. H. CHU

CONTENTS

Preface

This book is intended primarily to arouse the interests of graduate engineers, assistant engineers and engineers in the technical aspect of civil engineering works. The content of the book mainly focuses on providing the reasons of adoption of the various current practices of civil engineering. By understanding the underlying principles of engineering practices, graduate engineers/assistant engineers/engineers may develop an interest in civil engineering works and hence to make improvements to existing practices in civil engineering. It is also intended that the book will serve as a useful source of reference for practicing engineers.

The author is currently writing the book "200 Questions and Answers on Practical Civil Engineering Works Part II" and he sincerely invites the submission of civil engineering questions to email to *askvincentchu @yahoo.com.hk* to facilitate the completion of the book. For those questions selected by the author to be published in his new book, a free copy of the book shall be delivered to the author of those questions.

It is glad to publish this second edition of book. In this edition, many new topics (about 30 items) are introduced when compared with first edition which, I believe would further enrich the content of this book. Should you have any comments on the book, please feel free to send to my email *askvincentchu @yahoo.com.hk* and discuss.

Vincent T. H. CHU
April 2009

Chapter 1. Bridge Works

Advantages of continuous multiple-span deck over simply supported multiple-span deck

Movement joints are normally added to bridge structures to accommodate movements due to dimensional changes arising from temperature variation, shrinkage, creep and effect of prestress. However, the provision of excessive movement joints should be avoided in design because movement joints always encounter problems giving rise to trouble in normal operation and this increases the cost of maintenance.

Some designers may prefer to add more movement joints to guard against possible occurrence of differential settlements. However, the effect of continuity is disabled by this excessive introduction of movement joints.

From structural point of view, the use of continuous deck enhances the reduction of bridge deck thickness. Moreover, deck continuity allows the potential increase in headroom in the mid-span of bridges by using sucker deck principle.

Some designers may prefer to employ the use of simply supported multiple-span deck to guard against possible occurrence of differential settlements. However, the effect of continuity is undermined by the introduction of movement joints. In essence, the structural reserve provided by a continuous bridge is destroyed by the multiple-span statically determinate structure resulting from the addition of joints.

Moreover, the reduction of joints in bridge structures represents substantial cost savings arising from the construction and maintenance costs of movement joints. The reduction of deck thickness helps to cut the cost for both the deck and foundation. In particular, the number of bearings in each piers is substantially reduced when compared with the case of simply supported multiple-span deck.

*B*enefits of using the bridge form of precast prestressed beams supporting in-situ concrete top slab

The potential benefits of using the bridge form of precast prestressed beams supporting in-situ concrete top slab are:

(i) For bridges built on top of rivers and carriageway, this bridge form provides the working platform by the precast beams so that erection of falsework is not required.
(ii) This bridge form generally does not require any transverse beams or diaphragms (except at the location of bridge supports), leading to reduction of construction time and cost.
(iii) It creates the potential for simultaneous construction with several spans.

*C*oatings at the back faces of abutments

There are different views on the necessity of the application of protective coatings (may be in the form of two coats of paint) to the back faces of bridge abutment [30]. The main purpose of this coating serves to provide waterproofing effect to the back faces of abutments. By reducing the seepage of water through the concrete, the amount of dirty materials accumulating on the surface of concrete would be significantly decreased. Engineers tend to consider this as an inexpensive method to provide extra protection to concrete. However, others may consider that such provision is a waste of money and is not worthwhile to spend additional money on this.

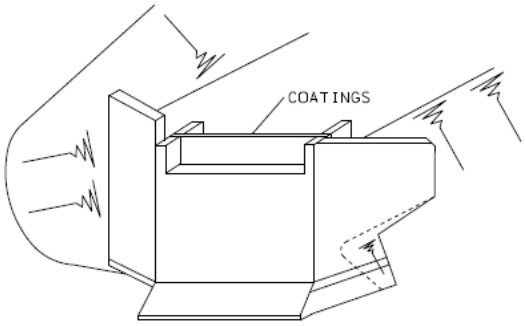

Fig. 1.1 Coatings at back faces of an abutment.

*D*imples in Polytetrafluoroethylene (PTFE)

PTFE is a flurocarbon polymer which possesses good chemical resistance and can function in a wide range of temperature. The most important characteristic of this material is its low coefficient of friction. PTFE has the lowest coefficients of static and dynamic friction of any solid with absence of stick-slip movement [43]. The coefficient of friction is found to decrease with an increase in compressive stress. However, PTFE do have some demerits like high thermal expansion and low compressive strength [43].

In designing the complementary contact plate with PTFE sliding surface, stainless steel plates are normally selected where the plates should be larger than PTFE surface to allow movement without exposing the PTFE. Moreover, it is recommended that the stainless steel surface be positioned on top of the PTFE surface to avoid contamination by possible accumulation of dirt and rubbish on the larger lower plates. Lubricants are sometimes introduced to reduce the friction between the PTFE surface and the upper stainless steel plate. Dimples are designed on PTFE surfaces to act as reservoirs for lubricant and these reservoirs are uniformly distributed over the surface of PTFE and normally they cover about 20%-30% of the surface area. Hence, the PTFE may be designed with dimples to avoid the lubricant from squeezing out under repeated translation movements.

*D*iscontinuity of joint – position of bearing

Expansion joints in a bridge structures cater for movements in transverse, longitudinal, vertical and rotational forms. The layout and position of expansion joins and bearings have to be carefully designed to minimize the future maintenance problem.

The position of bearings affects the discontinuity of a joint [43]. If the location of a bearing is too far away from a bridge joint, discontinuity of the joint would be experienced when there is an excessive angular rotation at the joint. Hence, by keeping the bearings and movement joints close in position, the discontinuity in the vertical direction can

be avoided.

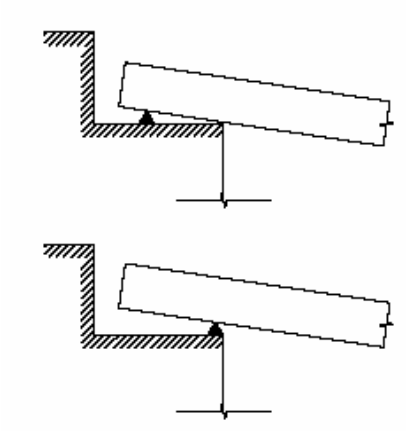

Fig. 1.2 The effect of position of bearing to the discontinuity of joint.

*D*iaphragms in bridges

The main function of diaphragms is to provide stiffening effect to deck slab in case bridge webs are not situated directly on top of bearings. Therefore, diaphragms may not be necessary in case bridge bearings are placed directly under the webs because loads in bridge decks can be directly transferred to the bearings [56]. On the other hand, diaphragms also help to improve the load-sharing characteristics of bridges. In fact, diaphragms also contribute to the provision of torsional restraint to the bridge deck.

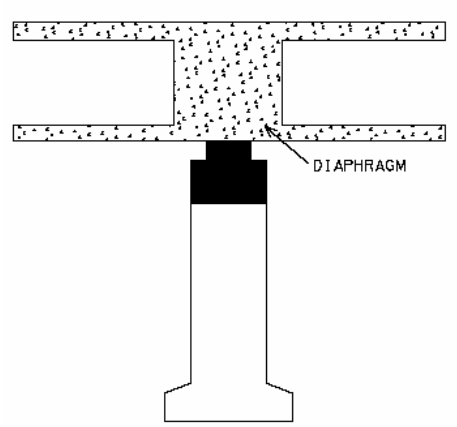

Fig. 1.3 Diaphragm.

*E*xcessive movement joints in bridges

Movement joints are normally added to bridge structures to accommodate movements due to dimensional changes arising from temperature variation, shrinkage, creep and effect of prestress. However, the provision of excessive movement joints should be avoided in design because movement joints always encounter problems giving rise to trouble in normal operation and this increases the cost of maintenance.

Some designers may prefer to add more movement joints to guard against possible occurrence of differential settlements. However, the effect of continuity is disabled by this excessive introduction of movement joints. In essence, the structural reserve provided by a continuous bridge is destroyed by the multiple-span statically determinate structure resulting from the addition of excessive joints.

*E*arth pressure on abutment

The magnitude of earth pressure coefficient in calculating the earth pressure on bridge abutment depends significantly on the degree of restraint provided by the abutment [30]. For example, active earth pressure is usually adopted for cantilever abutment because there is

possible occurrence of small relieving movements. However, for abutment founded on piles, the at-rest earth pressure can be assumed in assessing the earth pressure as the abutment is considered to be rigidly supported by piles and is fully restrained against lateral movement.

*E*ffect of bridge piers across a stream

The presence of bridge piers across a stream causes constricted flow in the openings because of the decrease of width of stream owing to the presence of the piers. Moreover, it creates the following problems from hydraulic point of view:

(i) Local scouring at the piers and bed erosion may take place. To avoid the damage to the foundation of piers, some protective layers of stone or concrete apron could be provided around the piers.
(ii) The head loss induced by the bridge piers causes the backwater effect so that the water level upstream is increased. Consequently, this may result in flooding in upstream areas.

*F*unctions of sleepers in railway

The functions of sleepers [7] in railway works are as follows:

(i) The primary function of a sleeper is to grip the rail to gauge and to distribute the rail loads to ballast with acceptable induced pressure.
(ii) The side functions of a sleeper include the avoidance of both longitudinal and lateral track movement.
(iii) It also helps to enhance correct line and level of the rails.

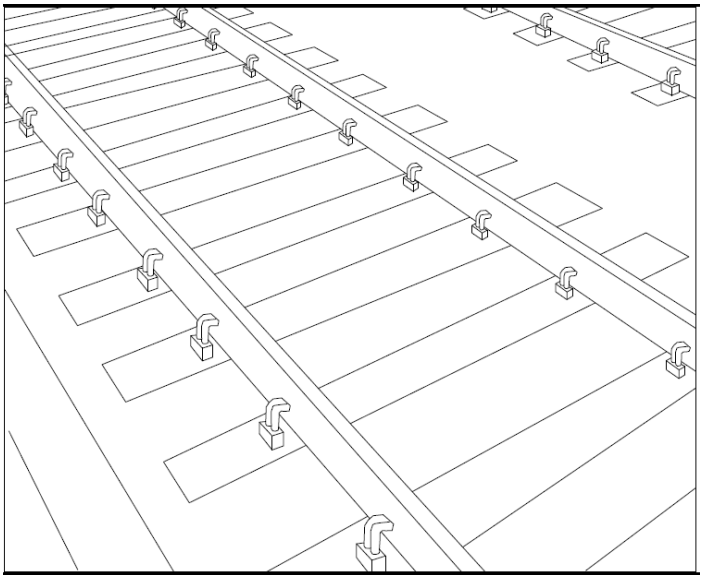

Fig. 1.4 Sleepers.

*J*oint continuity influenced by inclined bridge deck

Bearings are usually designed to sit in a horizontal plane so as to avoid the effect of additional horizontal force and uneven pressure distribution resulting from non-horizontal placing of bearings [43]. For an inclined bridge deck subject to a large longitudinal movement, a sudden jump is induced at the expansion joint and discontinuity of joint results. To solve this problem, an inclined bearing instead of a truly horizontal bearing is adopted if the piers can take up the induced horizontal forces.

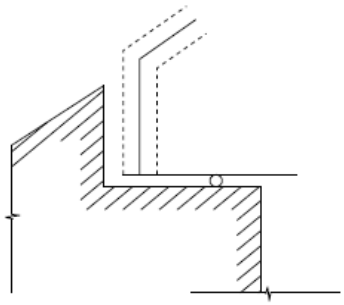

Fig. 1.5 The effect of inclined bridge deck on joint discontinuity.

*K*nife edge loads – representation of wheel axles?

In BS5400 the traffic loads for HA loading are given by the uniformly distributed loads along the loaded length and a knife edge load. In the code, it is not intended that knife edge loads simulate a wheel axle of vehicles [16]. Instead, it is just a tool to provide the same uniformly distributed loading to imitate the bending and shearing effects of actual traffic loads.

*L*imitations of grillage analysis

In designing the number of cells for concrete box girder bridges, in case the depth of a box girder bridge exceeds 1/6 or 1/5 of the bridge width, then it is recommended to be designed as a single cell box girder bridge. However, if the bridge depth is smaller than 1/6 of the bridge width, then a twin-cell or multiple cell is a better. However, one should note that even for wider bridges with small depths, the number of cells should be minimized because there is not much improvement in transverse load distribution when the number of cells of box girder is increased to three or more.

For structural analysis of bridges, grillage analysis, which involves the structure to be modeled as a series of longitudinal and transverse elements which are interconnected at nodes, is normally adopted.

Grillage analysis suffers from the following shortcomings:

(i) For coarse mesh, torques may not be identical in orthogonal directions. Similarly, twists may differ in orthogonal directions.
(ii) Moment in any beams is mainly proportional to its curvature only. However, moment in an element depends on the curvatures in the beam's direction and its orthogonal direction.

Grillage analysis cannot be used to determine the effect of distortion and warping. Moreover, the effect of shear lag can hardly be assessed by using grillage analysis. By using fine mesh of elements, local effects can be determined with a grillage. Alternatively, the local effects can be assessed separately and put in the results of grillage

analysis.

*L*ocal Scour at obstructions (e.g. bridge piers) in rivers

When the water flow in river is deflected by obstructions like bridge piers, scouring would occur arising from the formation of vortexes. The mechanism of formation of vortices is as follows: the flow hits the bridge piers and tends to move downwards. When the flow reaches the seabed, it would move in a direction opposite to its original flow direction before hitting the bridge piers. Hence, this movement of flow before the bridge piers results in the formation of a vortex. Owing to the formation of this vertical vortex, seabed material is continuously removed so that holes are formed at the seabed and this result in local scour at bridge piers. As the shape of vortices looks like horseshoes, it is sometimes called “horseshoe vortex”.

*M*ultiple-cell box girder: cells connected by top flanges vs cells connected both by top and bottom flanges

When the depth of a box girder bridge exceeds 1/6 or 1/5 of the bridge width, it is recommended to be designed as a single cell box girder bridge. However, if the bridge depth is smaller than 1/6 of the bridge width, then a twin-cell or multiple cell is a better choice [56]. However, even for wider bridges with small depths, the number of cells should be minimized because there is not much improvement in transverse load distribution when the number of cells of box girder is increased to three or more.

For multiple-cell box girders, there are generally two arrangements. The first one is that independent cells are connected by their top flanges only while the other one is that the cells are connected both at the top and bottom flanges. From the structural point of view, it is recommended to adopt the second arrangement. For the case of cells connected by top flanges only, their flanges are heavily stressed in the transverse direction owing to flexure which cannot be effectively distributed across the cross section.

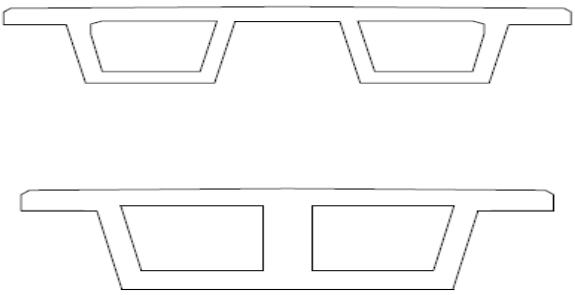

Fig. 1.6 Box girder with cells connected by top flanges and cells connected both by top and bottom flanges.

*O*ne-way prestressing vs two-way prestressing

During prestressing operation at one end, frictional losses will occur and the prestressing force decreases along the length of tendon until reaching the other end. These frictional losses include the friction induced due to a change of curvature of tendon duct and also the wobble effect due to deviation of duct alignment from the centerline. Therefore, the prestress force in the mid-span or at the other end will be greatly reduced in case the frictional loss is high. Consequently, prestressing, from both ends for a single span i.e. prestressing one-half of total tendons at one end and the remaining half at the other end is carried out to enable a even distribution and to provide symmetry of prestress force along the structure.

In fact, stressing at one end only has the potential advantage of lower cost when compared with stressing from both ends. For multiple spans (e.g. two spans) with unequal span length, jacking is usually carried out at the end of the longer span so as to provide a higher prestress force at the location of maximum positive moment. On the contrary, jacking from the end of the shorter span would be conducted if the negative moment at the intermediate support controls the prestress force. However, if the total span length is sufficiently long, jacking from both ends should be considered.

*O*verlays on concrete bridge deck

After years of servicing, some overlays may be applied on the top surface of bridges. Overlays on concrete bridge decks achieve the following purposes [8]:

(i) It aims to provide a smooth riding surface. Hence, it may be applied during the maintenance operation to hide the uneven and spalling deck surface and offers a smoother surface for road users.
(ii) The use of overlays can extend the life of the bridge deck.

*P*reset in bridge bearing

"Preset" is a method to reduce the size of upper plates of sliding bearings in order to save cost. The normal length of an upper bearing plate should be composed of the following components: length of bearing + 2 x irreversible movement + 2 x reversible movement. Initially the bearing is placed at the mid-point of the upper bearing plate without considering the directional effect of irreversible movement. However, as irreversible movement normally takes place at one direction only, the bearing is displaced/presetted a distance of (irreversible movement/2) from the mid-point of bearing in which the length of upper plate length is equal to the length of bearing + irreversible movement + 2 x reversible movement. In this arrangement, the size of upper plate is minimized in which irreversible movement takes place in one direction only and there is no need to include the component of two irreversible movements in the upper plate.

Note: "Preset" refers to the displacement of a certain distance of sliding bearings with respect to upper bearing plates during installation of bearings.

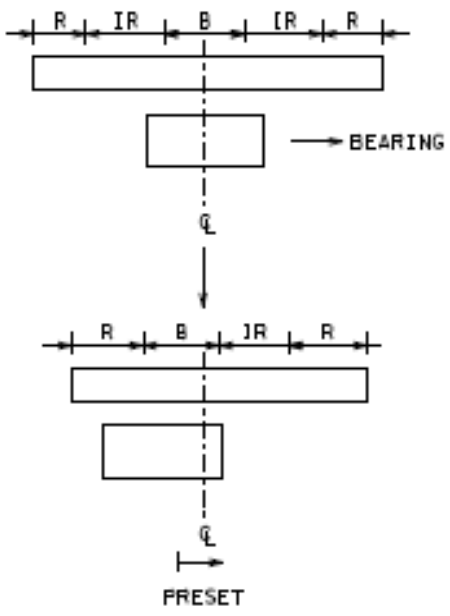

Fig. 1.7 Preset in sliding bearing.

*P*arasitic forces for prestressing

In statically determinate structures, prestressing forces would cause the concrete structures to bend upwards. Hence, precambering is normally carried out to counteract such effect and make it more pleasant in appearance. However, for statically indeterminate structures the deformation of concrete members are restrained by the supports and consequently parasitic forces are developed by the prestressing force in addition to the bending moment generated by eccentricity of prestressing tendons [53]. The developed forces at the support modify the reactions of concrete members subjected to external loads and produces secondary moments (or parasitic moments) in the structure.

*P*urpose of dowel bars in elastomeric bearing

Elastomeric bearing is normally classified into two types: fixed and free. For fixed types, the bridge deck is permitted only to rotate and

the horizontal movements of the deck are restrained. On the other hand, for free types the deck can move horizontally and rotate. To achieve fixity, dowels are adopted to pass from bridge deck to abutment. Alternatively, in case there is limitation in space, holes are formed in the elastomeric bearings where anchor dowels are inserted through these holes. It is intended to prevent the "walking" of the bearing during its operation.

*R*eason of loading on alternative spans to obtain maximum positive moment in a span of a continuous beam

To acquire a maximum sagging moment in a span of a continuous beam, the general rule is to load the span under consideration and alternative spans on each side of the span. To account for this rule, let's consider the following example. For instance, loads are applied to the mid-span of a multiple-span continuous beam. It is noticed that this loads induce positive moments near mid-span in all even spans. Therefore, if all even spans are loaded simultaneously, this will result in the increase of positive moments in all other loaded spans.

Similarly, to obtain maximum negative moment at a support, load adjacent spans of the support and then alternative spans on each side.

*S*hear lag in typical box-girder bridge

For multiple-cell box girders, there are generally two arrangements. The first one is that independent cells are connected by their top flanges only while the other one is that the cells are connected both at the top and bottom flanges. From the structural point of view, it is recommended to adopt the second arrangement. For the case of cells connected by top flanges only, their flanges are heavily stressed in the transverse direction owing to flexure which cannot be effectively distributed across the cross section.

In the structural analysis of bridges, shear lag have to be considered in design in some circumstances. Shear lag takes place when some parts of the cross section are not directly connected. For a box-girder bridge,

not all parts of flanges are joined directly to webs so that the connected part becomes highly stressed while the unconnected flanges are not fully stressed. In particular, for wide flanges of box-girder bridges axial loads are transferred by shear from webs to flanges which result in the distortion in their planes. Consequently, the plane sections do not stay plane and the stress distribution in the flanges are not uniform. Moreover, there is a tendency for longitudinal in-plane displacements of bride deck away from the flange/web connection to lag behind those parts of the bridge in close vicinity to the flange/web connection.

The effect of shear lag causes the longitudinal stress at flange/web connection to be higher than the mean stress across the flange. Therefore, the effect of shear lag has to be catered for in the design of box-girder bridges, especially for those with wide flanges.

Shear stiffness in elastomeric bearing

For elastomeric bearing, the shear stiffness is an important parameter for design because it influences the force transfer between the bridge and its piers. In essence, elastomers are flexible under shear deformation but it is relatively stiff in compression. However, elastomeric bearings should not be used in tension.

Elastomeric bearing should be designed in serviceability limit state only. The cross sectional area is normally determined by the compressive stress limit under serviceability limit state. The shape factor, i.e. plan area of the laminar layer divided by area of perimeter free to bulge, affects the relation between shear stress and the compressive load. In essence, higher capacity of bearings could be obtained with higher shape factor.

The long side of the bearing is usually oriented parallel to the principle axis of rotation because it facilitates rotational movement. The thickness of bearings is limited and controlled by shear strain requirements. In essence, the shear strain should be less than a certain limit to avoid the occurrence of rolling over at the edges and delamination due to fatigue. Hence, it follows that higher rotations and translations require thicker bearing. On the other hand, the vertical stiffness of bearings is obtained by inserting sufficient number of steel

plates. In addition, checks should be made on combined compression and rotation to guard against the possible occurrence of uplifting of corners of bearings under certain load combinations.

Shock transmission unit in bridges

Shock transmission unit is basically a device connecting separate structural units. It is characterized by its ability to transmit short-term impact forces between connecting structures while permitting long-term movements between the structures.

If two separate structures are linked together to resist dynamic loads, it is very difficult to connect them structurally with due allowance for long-term movements due to temperature variation and shrinkage effect [54]. Instead, large forces would be generated between the structures. However, with the use of shock transmission unit, it can cater for short-term transient loads while allowing long-term movements with negligible resistance. It benefits the bridge structures by acting as a temporary link between the structures to share and transfer the transient loads.

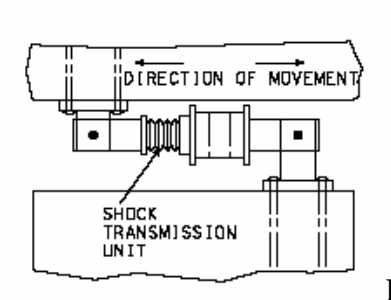

Fig. 1.8 Shock transmission unit.

Spalling reinforcement for prestressing works in anchor blocks

Reinforcement of anchor blocks in prestressing works generally consists of bursting reinforcement, equilibrium reinforcement and spalling reinforcement. Bursting reinforcement is used where tensile stresses are induced during prestressing operation and the maximum bursting stress occurs where the stress trajectories are concave towards

the line of action of the load. Reinforcement is needed to resist these lateral tensile forces. For equilibrium reinforcement, it is required where there are several anchorages in which prestressing loads are applied sequentially.

During prestressing, spalling stresses are generated in the region behind the loaded faces of anchor blocks [14]. At the zone between two anchorages, there is a volume of concrete surrounded by compressive stress trajectories. Forces are induced in the opposite direction to the applied forces and it forces the concrete out of the anchor block. On the other hand, the spalling stresses are set up owing to the strain compatibility relating to the effect of Poisson's ratio.

*S*tress corrosion of prestressing steel

Stress corrosion is the crystalline cracking of metals under tensile stresses in the presence of corrosive agents [44]. The conditions for stress corrosion to occur are that the steel is subjected to tensile stresses arising from external loading or internally induced stress (e.g. prestressing). Moreover, the presence of corrosive agents is essential to trigger stress corrosion. One of the main features of stress corrosion is that the material fractures without any damage observed from the outside. Hence, stress corrosion occurs without any obvious warning signs.

*T*ransition slabs in bridges

In some designs, transition slabs are provided on the approach to bridges. For instance, soils in embankment supporting the roads may settle due to insufficient compaction and sharp depressions would be developed at the junction with the relatively rigid end of bridge decks [53]. This creates the problem of poor riding surfaces of carriageway and proper maintenance has to be carried out to rectify the situation. As a result, transition slabs are sometimes designed at these junctions to distribute the relative settlements between the approaching embankments and end of bridge decks so that the quality of riding surface between these junctions could be significantly improved and

substantial savings could be obtained by requiring less maintenance.

*T*russ with K-bracing

In the arrangement of triangulated framework in truss structures, it is more economical to design longer members as ties while shorter ones as struts (e.g. Pratt truss). As such, the tension forces are taken up by longer steel members whose load carrying capacities are unrelated to their lengths. However, the compression forces are reacted by shorter members which possess higher buckling capabilities than longer steel members [34].

For heavy loads on a truss structure, the depth of the truss is intentionally made larger so as to increase the bending resistance and to reduce deflection. With the increase in length of the vertical struts, buckling may occur under vertical loads. Therefore, K-truss is designed in such as way that the vertical struts are supported by compression diagonals.

*V*ierendeel girder

The Vierendeel girder design is sometimes adopted in the design of footbridges. In traditional truss design, triangular shape of truss is normally used because the shape cannot be changed without altering the length of its members. By applying loads only to the joints of trusses, the members of truss are only subjected to a uniform tensile or compressive stress across their cross sections because their lines of action pass through a common hinged joint.

The Vierendeel truss/girder is characterized by having only vertical members between the top and bottom chords and is a statically indeterminate structure. Hence, bending, shear and axial capacity of these members contribute to the resistance to external loads. The use of this girder enables the footbridge to span larger distances and present an attractive outlook. However, it suffers from the drawback that the distribution of stresses is more complicated than normal truss structures [42].

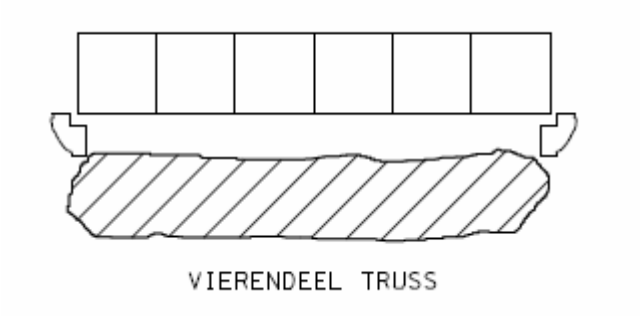

Fig. 1.9 Vierendeel Truss.

*W*aterproofing for bridge decks

Waterproofing materials like membranes are applied on top of bridge deck surface because:

(i) Vehicular traffic (e.g. tanker) may carry dangerous chemicals and the leakage of such chemicals in the absence of waterproofing materials may endanger the life of bridges. The chemicals easily penetrate and cause the deterioration of concrete bridge decks.
(ii) In some countries where very cold weather is frequently encountered, salt may be applied for defrosting purpose. In case waterproofing is not provided, the salt solution penetrates through the concrete cracks of the bridge and causes the corrosion of reinforcement.
(iii) In the event of cracks appearing on concrete deck, water penetrates the bridge deck and brings about steel corrosion.

*W*arren Truss, Howe Truss and Pratt Truss

A truss is a simple structure whose members are subject to axial compression and tension only and but not bending moment. The most common truss types are Warren truss, Pratt truss and Howe truss. Warren truss contains a series of isosceles triangles or equilateral triangles. To increase the span length of the truss bridge, verticals are added for Warren Truss.

Pratt truss is characterized by having its diagonal members (except the end diagonals) slanted down towards the middle of the bridge span. Under such structural arrangement, when subject to external loads tension is induced in diagonal members while the vertical members tackle compressive forces. Hence, thinner and lighter steel or iron can be used as materials for diagonal members so that a more efficient structure can be enhanced.

The design of Howe truss is the opposite to that of Pratt truss in which the diagonal members are slanted in the direction opposite to that of Pratt truss (i.e. slanting away from the middle of bridge span) and as such compressive forces are generated in diagonal members. Hence, it is not economical to use steel members to handle compressive force.

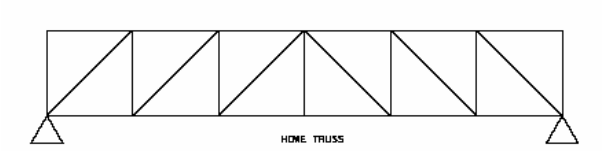

Fig. 1.10 A typical Howe Truss.

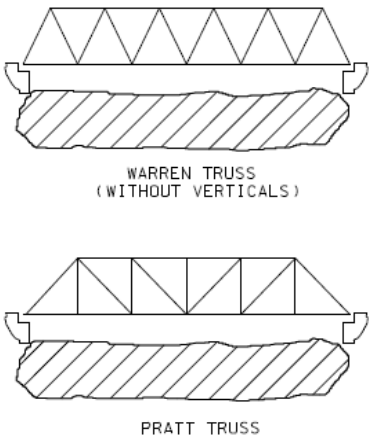

Fig. 1.11 Warren Truss and Pratt Truss.

Chapter 2. Concrete Works

Bond breaker for joint sealant

Joint sealant should be designed and constructed to allow free extension and compression during the opening and closure of joints. In case joint sealants are attached to the joint filler so that movement is prohibited, they can hardly perform their intended functions to seal the joints against water and debris entry. Polyethylene tape is commonly used as bond breaker tape.

To facilitate free movement, it can be achieved by adding bond breaker tape in-between the joint sealant and joint filler. Primers may be applied to the sides of joints to provide a good bond between them.

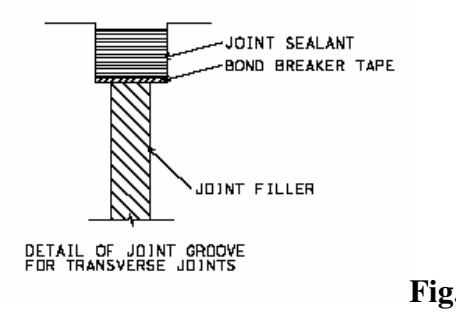

Fig. 2.1 Bond breaker tape for concrete joints.

Bonding performance to concrete: Epoxy-coated bars vs galvanized bars

Based on the findings of CEB Bulletin 211 [11], the bonding of galvanized bars to concrete is lower in early age owing to hydrogen release when zinc reacts with calcium hydroxide in concrete and the presence of hydrogen tend to reduce the bond strength between galvanized bars and concrete. However, bonding will increase with time until the full bond strength of ungalvanized bars is attained.

For epoxy-coated bars, there is a 20% decrease in bond strength for

bars placed at the bottom of concrete sections while for bars placed on the top there is no major difference in bond compared with uncoated bars.

*C*oating on concrete – complete impermeability to moisture?

In designing protective coating on concrete structures, stoppage of water ingress through the coating is normally required. Since chloride ions often diffuse into concrete in solution and cause deterioration of concrete structures, the prevention of water transmission into the coating certainly helps to protect the concrete structure. However, if water gets behind the coating from some means and becomes trapped, its effect may not be desirable. Firstly, vapour pressure would be developed behind the surface treatment and this leads to the loss of adhesion and the eventual peeling off of the coating. Moreover, the water creates a suitable environment for mould growth on concrete surface.

In fact, the surface treatment should be so selected that it is impermeable to liquid water but it is permeable to water vapour. This "breathing" function enhances the concrete to lose moisture through evaporation and reject the uptake of water during wet periods.

*C*rack width limitation (<0.5mm) = control reinforcement corrosion?

In many standards and code of practice of many countries, the allowable size of crack width is normally limited to less than 0.5mm for reinforced concrete structure to enhance the durability of concrete. The limitation of crack width can serve the aesthetic reason on one hand and to achieve durability requirement by avoiding possible corrosion of steel reinforcement on the other hand. Regarding the latter objective, site surveys and experimental evidence do not seem to be in favor of the proposition. Beeby [6] showed that there was no correlation between surface crack width (<0.5mm) and durability of reinforced concrete structure. In practice, most corrosion problems are triggered by the presence of surface cracks parallel to the

reinforcement instead of surface cracks perpendicular to the reinforcement.

Critical steel ratio – only consider 250mm of concrete from outer face

The purpose of critical steel ratio is to control the cracking pattern by having concrete failing in tension first. If steel reinforcement yields first before the limit of concrete tensile strength is reached, then wide and few cracks would be formed. In the calculation of critical steel ratio, the thickness of the whole concrete section is adopted for analysis. However, if the concrete section exceeds 500mm in thickness, only the outer 250mm concrete has to be considered in calculating minimum reinforcement to control thermal and shrinkage cracks [36]. It is because experimental works showed that for concrete section greater than 500mm, the outer 250mm on each face could be regarded as surface zone while the remaining could be regarded as core. The minimum reinforcement to control cracking should therefore be calculated based on a total maximum thickness of 500mm.

Corrosion protection of lifting anchors in precast concrete units

The corrosion of lifting anchors in precast concrete units has to be prevented because the corroded lifting units cause an increase in steel volume leading to the spalling of nearby surface concrete. Consequently, steel reinforcement of the precast concrete units may be exposed and this in turns results in the corrosion of steel reinforcement and the reduction in the load carrying capacity of the precast units. To combat the potential corrosion problem, the lifting anchors could be covered with a layer of mortar to hide them from the possible external corrosion agents. Alternatively, galvanized or stainless steel lifting anchors can be considered in aggressive environment.

*C*oncrete cover to enhance fire resistance

In the event of exposing the concrete structures to a fire, a temperature gradient is established across the cross section of concrete structures. For shallow covers, the steel reinforcement inside the structures rises in temperature. Generally speaking, steel loses about half of its strength when temperature rises to about 550^{o}C. Gradually, the steel loses strength and this leads to considerable deflections and even structural failure in the worst scenario. Hence, adequate cover should be provided for reinforced concrete structure as a means to delay the rise in temperature in steel reinforcement.

*D*ifferences between epoxy grout, cement grout and cement mortar

Epoxy grout consists of epoxy resin, epoxy hardener and sand/aggregates. In fact, there are various types of resin used in construction industry like epoxy, polyester, polyurethane etc. Though epoxy grout appears to imply the presence of cement material by its name, it does not contain any cement at all. On the other hand, epoxy hardener serves to initiate the hardening process of epoxy grout. It is commonly used for repairing hairline cracks and cavities in concrete structures and can be adopted as primer or bonding agent.

Cement grout is formed by mixing cement powder with water in which the ratio of cement of water is more or less similar to that of concrete [63]. Owing to the relatively high water content, the mixing of cement with water produces a fluid suspension which can be poured under base plates or into holes. Setting and hardening are the important processes which affect the performance of cement grout. Moreover, the presence of excessive voids would also affect the strength, stiffness and permeability of grout. It is versatile in application of filling voids and gaps in structures.

Cement mortar is normally a mixture of cement, water and sand (typical proportion by weight is 1:0.4:3). It is intended that cement mortar is constructed by placing and packing rather than by pouring. They are used as bedding for concrete kerbs in roadwork. They are

sometimes placed under base plates where a substantial proportion of load is designed to be transferred by the bedding to other members.

*D*isadvantages of excessive concrete covers

In reinforced concrete structures cover is normally provided to protect steel reinforcement from corrosion and to provide fire resistance. However, the use of cover more than required is undesirable in the following ways [25]:

(i) The size of crack is controlled by the distance of longitudinal bars to the point of section under consideration. The closer a bar is to this point, the smaller is the crack width. Therefore, closely spaced bars with smaller cover will give narrower cracks than widely spaced bars with larger cover. Consequently, with an increase in concrete cover the crack width will increase.
(ii) The weight of the concrete structure is increased by an increase in concrete cover. This effect is a critical factor in the design of floating ships and platforms where self-weight is an important design criterion.
(iii) For the same depth of concrete section, the increase of concrete cover results in the reduction of the lever arm of internal resisting force.

*E*ffect of concrete placing temperature on early thermal movement

The rate of hydration of cement paste is related to the placing temperature of concrete. The rate of heat production is given by the empirical Rastrup function:

$$H = H_o \times 2^{r(T-T1)}$$

H_o = Rate of heat production at a reference temperature
T = Temperature where rate of heat production H
T1 = Temperature where rate of heat production H_o
r = 0.084

An 12^{o}C increase in placing temperature doubles the rate of reaction of hydration. Hence, concrete placed at a higher temperature experiences a higher rise in temperature. For instance, concrete placed at 32^{o}C produces heat of hydration twice as fast when compared with concrete placing at 20^{o}C. Hence, high concrete placing temperature has significant effect to the problem of early thermal movement.

*E*ffect of rusting on steel reinforcement

The corrosion of steel reinforcement inside a concrete structure is undesirable in the following ways:

(i) The presence of rust impairs the bond strength of deformed reinforcement because corrosion occurs at the raised ribs and fills the gap between ribs, thus evening out the original deformed shape. In essence, the bond between concrete and deformed bars originates from the mechanical lock between the raised ribs and concrete. The reduction of mechanical locks by corrosion results in the decline in bond strength with concrete.
(ii) The presence of corrosion reduces the effective cross sectional area of the steel reinforcement. Hence, the available tensile capacity of steel reinforcement is reduced by a considerable reduction in the cross sectional area.
(iii) The corrosion products occupy about 3 times the original volume of steel from which it is formed. Such drastic increase in volume generates significant bursting forces in the vicinity of steel reinforcement. Consequently, cracks are formed along the steel reinforcement when the tensile strength of concrete is exceeded.

*F*ormation of pedestrian level winds around buildings

When a building blocks the wind blowing across it, part of the wind will escape over the top of the building. Some will pass around the edges of the building while a majority of the wind will get down to the ground. The channeling effect of wind for an escaping path, together with the high wind speeds associated with higher elevations, generates high wind speeds in the region at the base of the building. At the base

level of the building, there are three locations of strong pedestrian level winds:

(i) Arcade passages – wind flow is generated by the pressure difference between the front and the back of the building.
(ii) At the front of the building – high wind is produced by standing vortex.
(iii) At the corners of the building – high wind is induced by corner flow.

*G*GBS – cement replacement??

From structural point of view, GGBS replacement enhances lower heat of hydration, higher durability and higher resistance to sulphate and chloride attack when compared with normal ordinary concrete. On the other hand, it also contributes to environmental protection because it minimizes the use of cement during the production of concrete.

However, it is identified that there are still some hindrances that prevent the prevalence of its usage in local market. Technically speaking, GGBS concrete suffers from lower rate of strength development which is highly sensitive to curing conditions. In this connection, certain site measures have to be introduced to the construction industry to ensure better quality of curing process in order to secure high quality of GGBS concrete. On the other hand, designers have to be cautious of the potential bleeding problem of GGBS concrete.

Another major hurdle of extensive use of GGBS concrete lies in the little source of supply of GGBS. As Hong Kong is not a major producer of steel, GGBS as a by-product of steel has to be imported overseas and this introduces higher material cost due to transportation and the supply of GGBS is unstable and unsteady.

*I*ndirect tensile strength in water-retaining structures

The crack width formation is dependent on the early tensile strength of concrete. The principle of critical steel ratio also applies in this situation. The amount of reinforcement required to control early thermal and shrinkage movement is determined by the capability of reinforcement to induce cracks on concrete structures. If an upper limit is set on the early tensile strength of immature concrete, then a range of tiny cracks would be formed by failing in concrete tension [4]. However, if the strength of reinforcement is lower than immature concrete, then the subsequent yielding of reinforcement will produce isolated and wide cracks which are undesirable for water-retaining structures. Therefore, in order to control the formation of such wide crack widths, the concrete mix is specified to have a tensile strength (normally measured by Brazilian test) at 7 days not exceeding a certain value (e.g. 2.8N/mm^2 for potable water).

*J*oint filler in concrete expansion joints – a must??

The presence of joint filler is essential to the proper functioning of concrete joints though some may doubt its value. For a concrete expansion joint without any joint filler, there is a high risk of rubbish and dirt intrusion into the joint in the event that the first line of defense i.e. joint sealant fails to reject the entry of these materials. In fact, the occurrence of this is not uncommon because joint sealant from time to time is found to be torn off because of poor workmanship or other reasons. The presence of rubbish or dirt inside the joint is undesirable to the concrete structures as this introduces additional restraint not catered for during design and this might result in inducing excessive stresses to the concrete structure which may fail the structures in the worst scenario. Therefore, joint filler serves the purpose of space occupation so that there is no void space left for their accommodation. To perform its function during the design life, the joint filler should be non-biodegradable and stable during the design life of the structure to enhance its functioning. Moreover, it should be made of materials of high compressibility to avoid the hindrance to the expansion of concrete.

*L*ifting hoops in precast concrete – mild steel vs high yield steel

The strength of high yield steel is undoubtedly higher than mild steel and hence high yield steel is commonly used as main steel reinforcement in concrete structures. However, mild yield steel is commonly used in links or stirrups because they can be subjected to bending of a lower radius of curvature.

For lifting hoops in precast concrete, it is essential that the hoops can be bent easily and hence mild steel is commonly adopted for lifting hoops because high yield bars may undergo tension cracking when it is bent through a small radius.

*L*ap length > anchorage length

In some structural codes, the lap length of reinforcement is simplified to be a certain percentage (e.g. 25%) higher than the anchorage length. This requirement is to cater for stress concentrations at the end of lap bars. A smaller load when compared with the load to pull out an anchored bar in concrete triggers the splitting of concrete along the bar because of the effect of stress concentration. A higher value of lap length is adopted in design code to provide for this phenomenon.

*L*ongitudinal steel – an enhancement of shear strength

In addition to shear resistance provided by shear reinforcement, shear forces in a concrete section is also resisted by concrete compression force (compressive forces enhances higher shear strength), dowel actions and aggregate interlocking. The presence of longitudinal steel contributes to the enhancement of shear strength of concrete section in the following ways [46]:

(i) The dowelling action performed by longitudinal reinforcement directly contributes significantly to the shear capacity.
(ii) The provision of longitudinal reinforcement also indirectly controls the crack widths of concrete section which consequently affects the degree of interlock between aggregates.

*L*onger tension lap lengths at the corners and at the top of concrete structures

In BS8110 for reinforced concrete design, it states that longer tension lap lengths have to be provided at the top of concrete members. The reason behind this is that the amount of compaction of the top of concrete members during concrete placing is more likely to be less than the remaining concrete sections [49]. Moreover, owing to the possible effect of segregation and bleeding, the upper layer of concrete section tends to be of lower strength when compared with other locations.

When the lap lengths are located at the corners of concrete members, the degree of confinement to the bars is considered to be less than that in other locations of concrete members. As such, by taking into account the smaller confinement which lead to lower bond strength, a factor of 1.4 (i.e. 40% longer) is applied to the calculated lap length.

*L*ocation of lifting anchors in precast concrete units

It is desirable that the position of anchors be located symmetrical to the centre of gravity of the precast concrete units. Otherwise, some anchors would be subject to higher tensile forces when compared the other anchors depending on their distance from the centre of gravity of the precast concrete units. As such, special checks have to be made to verify if the anchor bolts are capable of resisting the increased tensile forces.

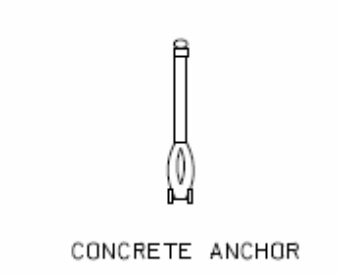

Fig. 2.2 A typical concrete anchor.

*L*ocation of construction joints

Construction joints are normally required in construction works because there is limited supply of fresh concrete in concrete batching plants in a single day and the size of concrete pour may be too large to be concreted in one go.

The number of construction joints in concrete structures should be minimized. If construction joints are necessary to facilitate construction, it is normally aligned perpendicular to the direction of the member. For beams and slabs, construction joints are preferably located at about one-third of the span length. The choice of this location is based on the consideration of low bending moment anticipated with relatively low shear force [10]. However, location of one-third span is not applicable to simply supported beams and slabs because this location is expected to have considerable shear forces and bending moment when subjected to design loads. Sometimes, engineers may tend to select the end supports as locations for construction joints just to simplify construction.

*M*easurement of cement and aggregates – by weight vs by volume

Measurement of constituents for concrete is normally carried out by weight because of the following reasons [55]:

(i) Air is trapped inside cement while water may be present in aggregates. As such measurement by volume requires the consideration of the bulking effect by air and water.
(ii) The accuracy of measurement of cement and aggregates by weight is higher when compared with measurement by volume when the weighing machine is properly calibrated and maintained. This reduces the potential of deviation in material quantity with higher accuracy in measurement for the design mix and leads to more economical design without the wastage of excess materials.

*M*ovement accommodation factor for joint sealant

Movement accommodation factor is commonly specified by manufacturers of joint sealants for designers to design the dimension of joints. It is defined as the total movement that a joint sealant can tolerate and is usually expressed as a percentage of the minimum design joint width [12]. Failure to comply with this requirement results in overstressing the joint sealants.

For instance, if the expected movement to be accommodated by a certain movement joint is 4mm, the minimum design joint width can be calculated as 4÷30% = 13.3mm when the movement accommodation factor is 30%. If the calculated joint width is too large, designers can either select another brand of joint sealants with higher movement accommodation factor or to redesign the arrangement and locations of joints.

*M*inimum distance between bars and maximum distance between bars

In some codes, a minimum distance between bars is specified to allow for sufficient space to accommodate internal vibrators during compaction.

On the other hand, the restriction of maximum bar spacing is mainly for controlling crack width [49]. For a given area of tension steel areas, the distribution of steel reinforcement affects the pattern of crack formation. It is preferable to have smaller bars at closer spacing rather than larger bars at larger spacing to be effective in controlling cracks. Hence, the limitation of bar spacing beyond a certain value (i.e. maximum distance between bars) aims at better control of crack widths.

*M*inimum area of reinforcement vs maximum area of reinforcement

Beams may be designed to be larger than required for strength

consideration owing to aesthetics or other reasons. As such, the corresponding steel ratio is very low and the moment capacity of pure concrete section based on the modulus of rupture is higher than its ultimate moment of resistance. As a result, reinforcement yields first and extremely wide cracks will be formed. A minimum area of reinforcement is specified to avoid the formation of wide cracks [49].

On the other hand, a maximum area of reinforcement is specified to enable the placing and compaction of fresh concrete to take place easily.

*M*ild steel vs high yield steel in water-retaining structures

In designing water-retaining structures, movement joints can be installed in parallel with steel reinforcement. To control the movement of concrete due to seasonal variation of temperature, hydration temperature drop and shrinkage etc. two principal methods in design are used: to design closely spaced steel reinforcement to shorten the spacing of cracks, thereby reducing the crack width of cracks; or to introduce movement joints to allow a portion of movement to occur in the joints.

For the choice of steel reinforcement in water-retaining structures, mild steel and high yield steel can both be adopted as reinforcement. With the limitation of crack width, the stresses in reinforcement in service condition are normally below that of normal reinforced concrete structures and hence the use of mild steel reinforcement in water-retaining structure will suffice. Moreover, the use of mild steel restricts the development of maximum steel stresses so as to reduce tensile strains and cracks in concrete.

However, the critical steel ratio of high yield steel is much smaller than that of mild steel because the critical steel ratio is inversely proportional to the yield strength of steel. Therefore, the use of high yield steel has the potential advantage of using smaller amount of steel reinforcement [49]. On the other hand, though the cost of high yield steel is slightly higher than that of mild steel, the little cost difference is offset by the better bond performance and higher strength associated with high yield steel.

*M*echanism of plastic settlement in fresh concrete

Within a few hours after the placing of fresh concrete, plastic concrete may experience cracking owing to the occurrence of plastic shrinkage and plastic settlement. The cause of plastic settlement is related to bleeding of fresh concrete. Bleeding refers to the migration of water to the top of concrete and the movement of solid particles to the bottom of fresh concrete. The expulsion of water during bleeding results in the reduction of the volume of fresh concrete. This induces a downward movement of wet concrete. If such movement is hindered by the presence of obstacles like steel reinforcement, cracks will be formed.

*N*o fines concrete

In some occasions no fines concrete is used in houses because of its good thermal insulation properties. Basically no fines concrete consists of coarse aggregates and cement without any fine aggregates. It is essential that no fines concrete should be designed with a certain amount of voids to enhance thermal insulation. The size of these voids should be large enough to avoid the movement of moisture in the concrete section by capillary action. It is common for no fines concrete to be used as external walls in houses because rains falling on the surface of external walls can only penetrate a short horizontal distance and then falls to the bottom of the walls. The use of no fines concrete guarantees good thermal insulation of the house.

*O*ver vibration of fresh concrete

For proper compaction of concrete by immersion vibrators, the vibrating part of the vibrators should be completely inserted into the concrete. The action of compaction is enhanced by providing a sufficient head of concrete above the vibrating part of the vibrators. This serves to push down and subject the fresh concrete to confinement within the zone of vibrating action.

Over-vibration should normally be avoided during the compaction of concrete. If the concrete mix is designed with low workability,

over-vibration simply consumes extra power of the vibration, resulting in the wastage of energy. For most of concrete mixes, over-vibration creates the problem of segregation in which the denser aggregates settle to the bottom while the lighter cement paste tends to move upwards [40]. If the concrete structure is cast by successive lifts of concrete pour, the upper weaker layer (or laitance) caused by segregation forms the potential plane of weakness leading to possible failure of the concrete structure during operation. If concrete is placed in a single lift for road works, the resistance to abrasion is poor for the laitance surface of the carriageway. This becomes a critical problem to concrete carriageway where its surface is constantly subject to tearing and traction forces exerted by vehicular traffic.

*P*ulverized fly ash as cement replacement – how it works?

Pulverized fly ash is a type of pozzolans. It is a siliceous or aluminous material which possesses no binding ability by itself. When it is in finely divided form, they can react with calcium hydroxide in the presence of moisture to form compounds with cementing properties.

During cement hydration with water, calcium hydroxide is formed which is non-cementitious in nature. However, when pulverized fly ash is added to calcium hydroxide, they react to produce calcium silicate hydrates which is highly cementitious. This results in improved concrete strength. This explains how pulverized fly ash can act as cement replacement.

*P*FA vs GGBS

(i) Similarities

Both GGBS and PFA are by-products of industry and the use of them is environmentally friendly. Most importantly, with GBS and PFA adopted as partial replacement of cement, the demand for cement will be drastically reduced. As the manufacture of one tonne of cement generates about 1 tonne of carbon dioxide, the environment could be conserved by using less cement through partial replacement of PFA

and GGBS.

On the other hand, the use of GGBS and PFA as partial replacement of cement enhances the long-term durability of concrete in terms of resistance to chloride attack, sulphate attack and alkali-silica reaction. It follows that the structure would remain to be serviceable for longer period, leading to substantial cost saving. Apart from the consideration of long-term durability, the use of PFA and GGBS results in the reduction of heat of hydration so that the problem of thermal cracking is greatly reduced. The enhanced control of thermal movement also contributes to better and long-term performance of concrete.

In terms of the development of strength, PFA and GGBS shared the common observation of lower initial strength development and higher final concrete strength. Hence, designers have to take into account the potential demerit of lower strength development and may make use of the merit of higher final concrete strength in design.

(ii) Differences Between GGBS and PFA

The use of GGBS as replacement of cement enhances smaller reliance on PFA. In particular, GGBS is considered to be more compatible with renewable energy source objectives.

The replacement level of GGBS can be as high as 70% of cement, which is about twice as much of PFA (typically replacement level is 40%). Hence, partial replacement of GGBS can enable higher reduction of cement content. As the manufacture of one tonne of cement generates about 1 tonne of carbon dioxide and it is considered more environmentally friendly to adopt GGBS owing to its potential higher level of cement replacement.

The performance of bleeding for GGBS and PFA varies. With PFA, bleeding is found to decrease owing to increased volume of fines. However, the amount of bleeding of GGBS is found to increase when compared with OPC concrete in the long term. On the other hand, drying shrinkage is higher for GGBS concrete while it is lower for PFA concrete.

In terms of cost consideration, the current market price of GGBS is similar to that of PFA. As the potential replacement of GGBS is much higher than PFA, substantial cost savings can be made by using GGBS.

*P*urpose of setting minimum amount of longitudinal steel areas for columns

In some design codes it specifies that the area of longitudinal steel reinforcement should be not less than a certain percentage of the sectional area of column. Firstly, the limitation of steel ratio for columns helps to guard against potential failure in tension. Tension may be induced in columns during the design life of the concrete structures. For instance, tension is induced in columns in case there is uneven settlement of the building foundation, or upper floors above the column are totally unloaded while the floors below the column are severely loaded. Secondly, owing to the effect of creep and shrinkage, there will be a redistribution of loads between concrete and steel reinforcement. Consequently, the steel reinforcement may yield easily in case a lower limit of steel area is not established.

In addition, test results showed that columns with too low a steel ratio would render the equation below inapplicable which is used for the design of columns:

$N=0.67f_{cu}A_c+f_yA_s$

*P*urpose of reducing the seasonal and hydration temperature by one-half in the calculation of crack widths arising from thermal movement

In the calculation of thermal movement, the following formula is used in most codes:

$w_{max}=s \times a \times (T_1+T_2)/2$

where w_{max} = maximum crack width
s = maximum crack spacing

a = coefficient of thermal expansion of mature concrete

T_1= fall in temperature between peak of hydration and ambient temperature

T_2= fall in temperature due to seasonal variation

For T_1, it represents the situation when the freshly placed concrete is under hydration process. Since the occurrence of high creep strain to the immature concrete tends to offset the effect of early thermal movement, a factor of 0.5 is purposely introduced to take into account such effect.

For T_2, it refers to the seasonal drop in temperature for the mature concrete. Owing to the maturity of concrete in this stage, the effect of creep on concrete is reduced accordingly. Since the ratio of tensile strength of concrete (f_{ct}) to average bond strength between concrete and steel (f_b) increases with maximum crack spacing, the lower values of f_{ct}/ f_b in mature concrete leads to smaller crack spacing. Therefore, the increased number of cracks helps to reduce the effect of thermal movement brought about by seasonal variation. Hence, T_2 is reduced by one-half to cater for further creep and bond effects in mature concrete.

*R*elation of pouring rate and temperature with concrete pressure on formwork

Freshly placed concrete exerts pressure on formwork during the placing operation. It is influenced by the rate of placing and the air temperature. For instance, if the concrete pouring rate is too slow, setting of concrete starts to take place. As a result, the concrete at the bottom of the formwork sets prior to the placing of fresh concrete at the top and the maximum pressure will be reduced.

Temperature affects the rate of hydration of concrete. The higher the air temperature is, the higher will be the rate of hydration reaction. Consequently, fresh concrete tends to set at a faster rate. The pressure exerted on formwork decreases with an increase in temperature. For this reason, formwork is subjected to a higher pressure exerted by fresh concrete in winter than in summer.

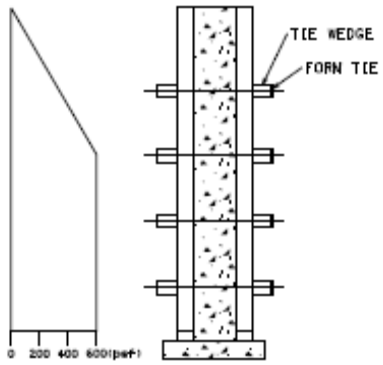

Fig. 2.3 Diagram of design concrete pressure diagram on formwork.

*R*einforcement of concrete in contact with internal vibrators

During concreting, if internal vibrators are placed accidentally in contact with some of the reinforcement bars, some undesirable effects may result. The most obvious one is that the reinforcement bars may become damaged or displaced if loosely tied.

Air bubbles tend to move towards the source of vibration. For poker vibrators touching the reinforcement bars, air pockets may be trapped in the vicinity of the reinforcement because the vibration generated by internal vibrators attracts these air bubbles. Consequently, the bond between the reinforcement and surrounding concrete would be impaired.

To produce good surface finish close to densely-packed reinforcement cage, workers may insert the poker vibrators in the gap between the reinforcement cage and formwork because the reinforcement cage tend to damp down the vibration effect when the vibrators are placed at a distance from the formwork. However, concentrated vibration within the cover region causes the migration of finer cement mortar to this region and results in changes in concrete colour. If the concrete cover is small, the chance of getting the poker vibrators jammed within the gap is high and the formwork is likely to be damaged by the vibrators.

*R*easons for blockage in pumping concrete

Concrete pumping is commonly adopted in highly elevated locations for which access for concrete trucks is difficult. Construction works can be speeded up by using concrete pumping because a larger volume of pours can be achieved within a specified duration when compared with normal concrete placing methods.

Blockage may occur during pumping operation for the following two common reasons [18]:

(i) For saturated concrete mixes, the pump pressures may force water out of the concrete resulting in bleeding. The flow resistance is then increased and may contribute to the blockage of pipelines.

(ii) If the cement content (or other components of concrete mixes that increase the frictional forces) is high, a higher frictional resistance to pumping may develop and the concrete may not be pumpable.

*R*etardation of fresh concrete

Retardation of fresh concrete has several advantages as follows:

(i) A rapid hydration process results in loss in concrete strength because the concrete will have a poorer structure with a higher gel/space ratio compared with the concrete with a lower hydration rate.
(ii) During the hydration process, ~~a~~ substantial heat of hydration will be generated. If the hydration process is carried out too swiftly, it will cause a rapid rise in temperature and result~~s~~ in considerable early thermal movement in concrete.
(iii) In hot weather concreting, the loss of workability is substantial. In order to ensure sufficient compaction of fresh concrete, it is necessary to extend the time for fresh concrete to remain plastic.

*S*tandard mixes of concrete

In some countries like Britain, specification for concrete does not

normally require cube tests for standard mixes of concrete. The quality control of standard mixes in Britain is achieved by checking if the appropriate mix proportions are adopted during the mixing of concrete. However, in Hong Kong the requirement of testing for compressive strength is still required for standard mixes in the specification because it is impractical to inspect and check all constituent materials (e.g. cement, aggregates etc.) for concrete for compliance. As there is high variability in mixing materials owing to variance in the origin of production of constituent materials in Hong Kong, there is a risk that the end-product concrete does not comply with the design requirements even though the mix proportions of standard mixes are followed closely by engineers.

Shear slump vs collapse slump in slump test

There are three types of slump that may occur in a slump~~s~~ test, namely, true slump, shear slump and collapse slump.

True slump refers to general drop of the concrete mass evenly all around without disintegration.

Shear slump indicates that the concrete lacks cohesion. It may undergo segregation and bleeding and thus is undesirable for the durability of concrete [46].

Collapse slump indicates that concrete mix is too wet and the mix is regarded as harsh and lean.

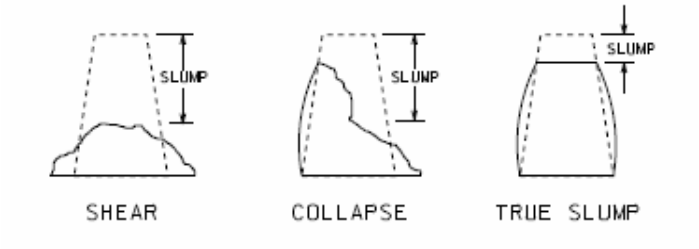

Fig. 2.4 Type of concrete slump

*S*ealing moving cracks and non-moving cracks

In devising a suitable method to seal up cracks detected on concrete surface, it is of paramount importance to determine if further movement would be expected for the cracks. If the crack is not expected to move further, it is sufficient to brush cement grout into it. For wider cracks, other materials like latex-cement mixture may be considered for sealing the crack.

When further movement is expected for the crack, seals wider than the cracks are recommended to be applied over the crack in order to reduce the strain around it to an acceptable level. Moreover, it is desirable to apply the treatment when the cracks are widest so that the sealing material is not subject to further extension. Care should be taken to prevent bonding of sealing material with the bottom of the crack to ensure that only direct tension forces are experienced in the sealing material.

*T*ime to remove formwork to cater for early thermal movement

Let us take a circular column as an example to illustrate effect of internal restraint to thick sections.

When the temperature is rising, temperature in the core is higher than that at outer zone. The inner core will have a higher expansion and exert pressure to the outside. The induced compressive stress will result in the formation of radial cracks near the surface of concrete.

When the temperature drops, the concrete at the outside drops to surrounding temperature while the concrete at the central region continues to cool down. The contraction associated with inner concrete induces tensile strains and forms cracks tangential to the circular radius.

It is beneficial for thick sections (say >500mm) to have late removal of formwork to reduce early thermal cracking. This is to allow more time for the centre of concrete section to cool down gradually to reduce the risk of thermal cracking. This is effective in controlling the

temperature differential across the cross section of the concrete structures and reducing the potential of internal cracking due to early thermal movement.

*T*ension anchorage length vs compression anchorage length

Tension anchorage length of steel reinforcement in concrete depends on bond strength. When steel reinforcement is anchored to concrete and is subjected to compressive forces, the resistance is provided by the bond strength between concrete and steel and the bearing pressure at the reinforcement end. Tension lap length is generally longer than compression lap length. In some design codes, instead of permitting the use of bearing pressure at reinforcement ends, the allowable ultimate bond stress is increased when calculating compression anchorage length.

*T*ension reinforcement leads to increasing deflection in concrete structures?

In BS8110 a modification factor is applied to span/depth ratio to take into account the effect of tension reinforcement. In fact, deflection of concrete structure is affected by the stress and the amount of tension reinforcement. To illustrate their relationship, let's consider the following equation relating to beam curvature:

Curvature = $1/r = e/(d-x)$

where r = radius of curvature
e = tensile strain in tension reinforcement
d = effective depth
x = depth of neutral axis

Provided that the tensile strain in tension reinforcement remains constant, the curvature of concrete structure increases with the depth of neutral axis. It is observed that the depth of neutral axis rises with tension steel ratio. Therefore, the curvature of concrete section is directly proportional to the tension steel ratio. In addition, the larger

value of the depth of neutral axis enhances increased area of concrete compression so that the effect of creep on deflection appears to become significant.

*U*se of primers in joint sealant

Most joint sealants applied in concrete joints are adhesive and the recommended joint width/depth of joint sealant is from 2:1 to 1:1 as given by BS6213 and Guide to Selection of Constructional Sealants. When joint sealant is applied on top of joint filler in concrete joints, additional primers are sometimes necessary because [12]:

(i) Primers help to seal the surface to prevent chemical reaction with water;
(ii) It provides a suitable surface for adhesion of joint sealant.

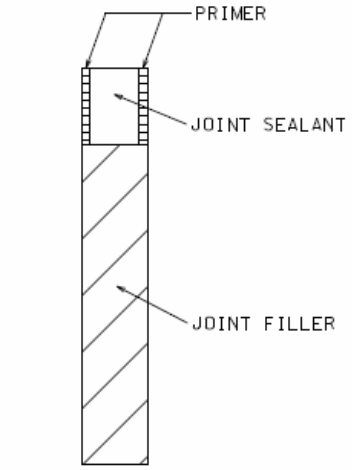

Fig. 2.5 Primer in joints.

*V*ibration in structures – resilient bearings

When railway tunnels are built close to buildings, ground-borne vibration is transmitted to the building by means of compression and shear waves [36]. When structural members (e.g. wall) of a building have natural frequencies similar to the frequency at the source, the response of the structures would be magnified. This effect is even

more significant when the building is designed with small number of movement joints. Consequently, the vibration can be felt inside the building and noise associated with such vibration is produced. To avoid this, vibration isolation can be implemented, sometimes by providing resilient bearings at column heads in buildings.

Chapter 3. Drainage Works

Application of embankment condition for drainage design

In considering the loads on buried pipeline, there are normally two scenarios: narrow trench condition and embankment (wide trench) condition [23].

For narrow trench condition, when the pipe is laid in a relatively narrow trench with backfill properly compacted, the weight of fill is jointly supported by both the pipe and the frictional forces along the trench walls. For embankment condition, the fill directly above settles less than the fill on the side. Consequently, loads are transferred to the pipeline and the loads on pipeline are in excess of that due to the fill on pipeline.

The narrow trench condition is used where excavation commences from the natural ground surface without any fills above the surface. On the contrary, the embankment condition applies where the pipes are laid at the base of fill. For instance, embankment condition is normally adopted where the pipes are laid partly in trench or partly in fill or poor foundations to pipes are encountered so that the trenches have to be excavated wider than the minimum requirement.

Best hydraulic section

The best hydraulic section of an open channel is characterized by provision of maximum discharge with a given cross sectional area. As such, channels with circular shape is the best hydraulic sections while a rectangular channel with channel width being equal to two times the height of channel is the best hydraulic section among all rectangular sections. In fact, the choice of best hydraulic section also possesses other advantages than hydraulic performance. For instance, for a given discharge rate the use of best hydraulic section could guarantee the least cross sectional area of the channels. Substantial savings could be made from the reduction in the amount of excavation and from the use

of less channel linings.

*C*olebrook White formula suitable for shallow gradient of pipes?

Manning's Equation is commonly used for rough turbulent flow while Colebrook-White Equation is adopted for transition between rough and smooth turbulent flow.

For Manning's Equation, it is simple to use and has proven to have acceptable degree of accuracy and is the most commonly used flow formula in the world. When using Colebrook-White Equation, it is observed that for very flat gradient (i.e. <1.5%) it tends to underestimate the flow because as gradient approaches zero, velocity also approaches zero. Hence, care should be taken when using Colebrook-White Equation for flat gradients.

*C*oncrete surround for drainage pipes

Concrete surround is normally adopted for rigid drainage pipes to resist high traffic loads (e.g. under shallow covers) and to allow for using pipes with lower strength. Moreover, the use of concrete surround can minimize settlement of adjacent structures. In addition, the highest possible accuracy in levels and gradient can be achieved by using concrete surround as considerable settlement is expected in other types of beddings like granular bedding.

The distribution of reinforcement in concrete pipes may not be uniform owing to the occurrence of tensile stresses in different locations around the circumference of the pipes [67]. For instance, tensile stresses are highest at the inner face of pipes at invert and crown levels and at the outer face of the two sides of pipes. An elliptical cage may be designed in order to optimize the usage of steel reinforcement.

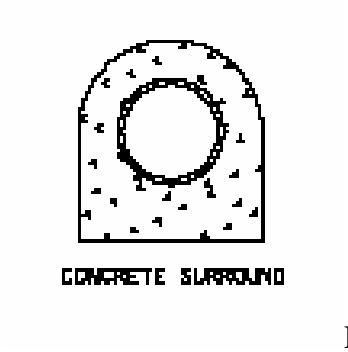

Fig. 3.1 Concrete surround of drains.

*D*ifference between road gullies and catchpits

Both road gullies and catchpits are the two basic types of drainage inlets of drainage system. Though they are designed to catch stormwater, road gullies and catchpits are intended to catch stormwater at different locations. Catchpits are designed to receive stormwater from slopes and stream courses. There is no standard design of catchpits and they can take different forms and shapes like inclusion of sand trap to improve the quality of collected stormwater and to prevent the blockage of drains. On the other hand, road gullies are intended to receive stormwater from roads only.

*D*rainage pipes in reclamation areas

In reclamation areas drainage pipes are usually laid at flatter gradients when compared with upstream stormwater pipes. The fact that the nature of flow in stormwater drain is by gravity makes the downstream pipes in reclamation areas relatively deep below ground surface. It is preferable to have outfall of drains above the tidal influence level and this accounts for the relative flatter gradient of drain pipes in reclamation area.

Attention has to be paid to the possible occurrence of differential settlement in reclamation area. For pavement design, flexible pavement is preferred to rigid pavement to cater for settlement problems. Similarly, in the design of drains flexible joints like spigot

and socket joints and movement joints in box culverts have to be provided to guard against the effect of differential settlement.

*E*ffects of sewer sediment on hydraulic performance

The presence of sediment in sewers has adverse effects on the hydraulic performance of sewers [13]. For the case of sewage flow carrying sediment without deposition, the presence of sediment in the flow causes a small increase in energy loss.

In case the sewer invert already contains a bed of sediment deposit, it reduces the cross sectional area of sewers and consequently for a given discharge the velocity increases. As such, the head losses associated with this velocity increase. Moreover, the increase in bed resistance induced by the rough nature of sediment deposit reduces the pipe flow capacity of sewers.

For sewers which are partially full, the presence of sediment bed enhances higher frictional resistance and results in increasing the flow depths and subsequent decrease of velocity. The reduction of velocity will lead to further deposition of sediment owing to the decrease of sediment carrying capacity if the increase of capacity of sewers generated by the presence of sediment bed does not exceed the reduction in flow caused by the bed roughness.

*E*nergy dissipation at outlets

Flow velocity at outlets is usually high. Without proper control of this energy, the subsequent bank erosion may result in failure of the banks. Therefore, some energy dissipating structures are designed to cope with this problem. Impact energy dissipaters may be provided at outlets by making use of impact walls to dissipate energy. Alternatively, the flows at outlet are dispersed artificially to achieve a significant loss of energy. However, the problem of cavitation may occur in this type of energy dissipating structures.

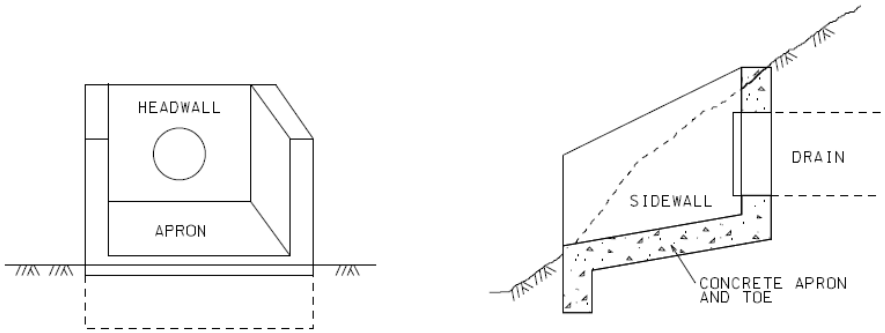

Fig. 3.2 A typical drainage outlet.

*F*unctions of hydraulic jump

The use of hydraulic jump in hydraulic engineering is not uncommon and the creation of such jumps has several purposes [58]:

(i) Its main aim is to perform as an energy-dissipating device to reduce the excess energy of water flows.
(ii) The jump generates significant disturbances in the form of eddies and reverse flow rollers to facilitate mixing of chemicals.
(iii) During the jump formation, considerable amount of air is entrained so that it helps in the aeration of streams which is polluted by bio-degradable wastes.
(iv) It enables efficient operation of flow measuring device like flumes.

*F*ull bore flow in drainage design

In the design of gravity drainage pipes, full bore flow capacity is normally adopted to check against the design runoff. However, one should note that the maximum flow rate does not occur under full bore conditions. The maximum discharge occurs when the water depth in circular pipes reaches 93.8% of the pipe diameter. Therefore, the use of full bore discharge is on the conservative side though the pipe's maximum capacity is not utilized.

Similarly, the maximum velocity does not occur in full bore conditions

and for circular pipes it occurs when the water depth is 81.3% of the pipe diameter. Hence, in checking for the maximum velocity of flow in pipes to avoid possible erosion by rapid flow, the use of full-bore velocity may not be on the conservative side.

*F*unctions of wetwells

Wetwells are designed to store temporarily water/sewage before it is pumped out. They are usually provided for sewage and stormwater pumping stations and they serve the following functions:

(i) They assist in attenuating the fluctuations of flow owing to the diurnal variation of sewage discharge.
(ii) The wetwells serve as sump pits where the suction pipes are inserted and the fluid level in the sumps can be employed for the control of opening and closure of pumps.

*J*oints in box culverts and channels - necessity of watertightness

The joints for box culverts and channels should be capable of accommodating movements arising from temperature and moisture changes. However, the joints are not necessarily designed as watertight except the following conditions [15]:

(i) There is a high possibility of occurrence of high water table in the vicinity of box culverts/channels. The high groundwater level and rainwater seepage through embankment may cause water passing through the joints and washing in soils. Consequently, the loss of soils may lead to the failure of the structures.
(ii) If the box culvert/channels are designed in such a way that water flow through joints from the structures causes the washing out of bedding materials, the requirement of watertightness of joint has to be fulfilled.
(iii) In cold countries, road salt is sometimes applied on roads above box culvert or at crossings of channels to prevent freezing and thawing. The leaching of road salts into the joints may cause corrosion of joint reinforcement.

*M*anhole covers – triangular halves

Manhole covers are generally made up of two pieces of triangular plates to form a square cover [23]. One may wonder why two rectangular halves are used for a rectangular cover. To understand this, one should note that a triangular cover could simply lie on a plane while a rectangular cover contains a point of redundancy. Hence, the potential problem of rocking produced by vehicular traffic by rectangular traffic could be eliminated by using two triangular halves.

Other the other hand, the two pieces of triangular covers should be bolted together. As for a piece of triangular cover, it is easily dropped into the rectangular hole of manhole during routine maintenance. Therefore, from maintenance point of view, some countries prefer another geometrical shape i.e. circular, as this is the only shape that the cover could hardly be accidentally dropped into the manhole. On the other hand, for other geometrical shapes such as rectangle or square, they could still be dropped into their formed hole when inclined into proper angles.

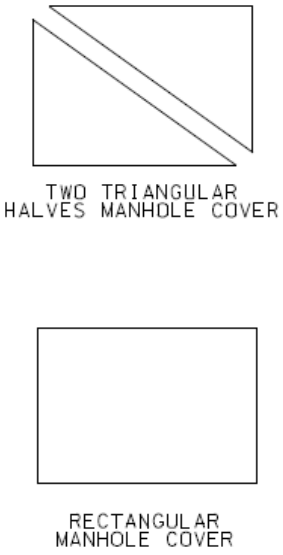

Fig. 3.3 Different types of manhole covers.

*M*anhole loss

Manholes are provided in locations where there are changes in size, direction and gradient of gravity pipelines. In normal practice for straight pipelines manholes have to be installed at a certain spacing to facilitate the maintenance of pipes. With the introduction of manholes, there are various reasons which account for the manhole loss [9]:

(i) The sudden expansion of inflow into manholes and the sudden contraction of flow out of manholes lead to significant energy losses.
(ii) It is not uncommon that several pipes may be connected to the same manhole. As such, the intermixing of flow takes place inside the manhole and this leads to head losses.
(iii) Flow inside the manholes may be designed to change directions which contribute to additional losses.

*N*ecessity of reinforcement in precast concrete manhole units

Precast concrete manholes are normally constructed by placing the bases of manholes firstly. The walls of precast manholes are formed by placing the precast concrete rings one on top of the other up to the required height. Someone may notice that reinforcement used for resisting the lateral earth pressure and surface loads are not considered in some design. It is discussed in Concrete Pipe Association of Great Britain that analysis of soil pressures shows that standard unreinforced precast units are capable of resisting uniformly distributed pressures (e.g. loading condition in a manhole) down to a depth of 150m. If very severe road traffic and side loads are encountered, an additional concrete surround of about 150mm may be provided.

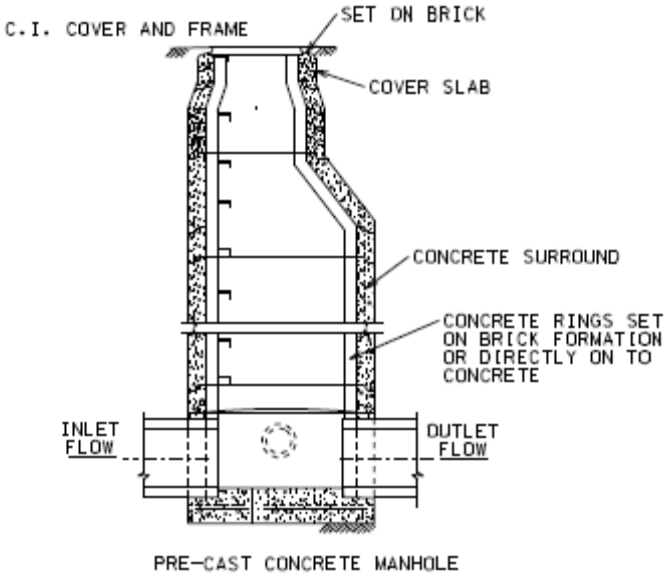

Fig. 3.4 A precast concrete manhole.

*O*n-line storage vs off-line storage

The design of storage pond is commonly divided into on-line storage and off-line storage. The on-line storage concept involves inclusion of storage facilities in series with the pipelines so that overflow at the storage facilities is allowed. One simple application of on-line storage is to enhance a large size of drainage pipes. However, for heavy rainfall situation, the spare capacity of drainage pipes will be rapidly exhausted. On the other hand, off-line storage (e.g. underground storage tank) refers to storage facilities in parallel with the pipeline and the return flow to the main pipeline is only allowed when the outflow pipelines are not surcharged.

*P*ossible defaults for precast concrete pipes made by spinning and vertical casting

Small diameter precast concrete pipes are normally manufactured by spinning method. The spinning method basically makes use of the principle of centrifugal forces which diminishes towards the centre of precast pipe. Hence, problems like the presence of voids and variation of dimension occur frequently and remedial works like filling of voids by cement mortar has to be carried out depending on the severity of deficiency.

Large diameter precast concrete pipes are commonly produced by vertical casting method [67]. In this method the concrete pipes are normally placed upright with spigot staying on top, resting on socket moulds before the freshly-placed concrete has set. There is a possibility of deformation of pipe spigots to form oval shapes.

*P*urpose of granular bedding for concrete pipes

In designing the bedding for concrete drainage pipes, granular materials are normally specified instead of soils containing a wide range of different particle sizes. The main reason of adopting granular material free of fine particles is the ease of compaction as it requires very little tamping effort to achieve a substantial amount of compaction and the crushed aggregates readily move to suitable place around the pipes [67]. However, the use of granular materials has the drawback that a stable support can hardly be provided for the drainage pipes. In particular, it cannot maintain an accurate slope and level for the bedding of concrete pipes. Most pipes are gravity pipes and the accuracy in level is essential to maintain the flow capacity.

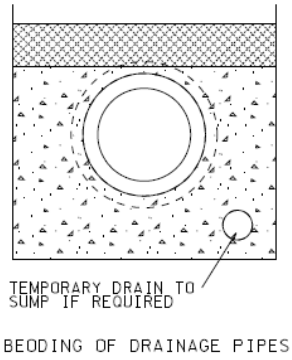

Fig. 3.5 Bedding of concrete pipes.

*P*urpose of carrying out water absorption test for precast concrete pipes

Cement will mix with more water than is required to eventually combine during hydration of cement paste. As such, some voids will be left behind after the hydration process which affects the strength and durability of concrete. With the presence of air voids in concrete, it is vulnerable to penetration and attack by aggressive chemicals. Good quality concrete is characterized by having minimal voids left by excess water and therefore, water absorption test for precast concrete pipes is adopted for checking the quality of concrete in terms of density and imperviousness.

*R*eason in checking the ratio (i.e. design flow to full-bore flow > 0.5) in circular pipe design

For checking of self-cleansing velocity for pipes, there is another criterion to check design flow Q to full bore flow Q_{full}> 0.5. If this criterion is met, it can be deduced that the design flow is always greater than self-cleansing velocity.

The reason behind is that from the chart of circular pipes, when Q/ Q_{full} >0.5, then the ratio of design velocity V to full bore velocity V_{full} >1. After confirming V_{full} >1m/s, then it leads to V>1m/s. Hence, minimum velocity at full bore flow should be checked.

*R*elation of the angle of contact between pipe invert and bedding material to the load resisting capacity of pipe

Minimum crushing strength is a commonly adopted parameter for describing the strength of rigid pipes like concrete pipes. This value is determined in laboratory by subjecting the test concrete pipe to a line load diametrically along the pipe length while the pipe invert is supported on two bearers for stability reason. This test is called three-edge bearing test and the load at failure of pipes is expressed in terms of kN per length of test pipes (called minimum crushing strength).

Bedding factor of a pipe is defined as the failure load for the pipe laid in actual ground with bedding to the failure load under three-edge bearing test. The bedding factor is largely related to the angle of contact between pipe invert and the bedding material. The angle of contact between pipe invert and the bedding material increases with the ratio of bending moment at invert (for the case of three-edge bearing test) to the angle under consideration [67].

*R*ubber dams – air-filled vs water-filled

Most of the existing rubber dams are of air-filled types. Water-filled rubber dams are not preferred for the following reasons:

(i) By giving the same sheet length and dam height, the tensile stress for water-filled dams is higher than that of air-filled rubber dams.
(ii) A significant size of water pond is normally provided for water-filled water dams for filling the rubber dams during the rising operation of dams.

*S*ingle-cell box culvert vs double-cell box culvert

The use of double-cell box culverts is preferred to single-cell box culverts for cross-sectional area larger than about $5m^2$ owing to the following reasons:

(i) Where there is tight headroom requirement, the use of double-cell box culvert can shorten the height of culverts by having a wider base so that the same design flow can be accommodated.
(ii) The invert of one cell can be designed at a lower level to cater for low flow condition so that it reduces the occurrence of sediment deposition and avoid the presence of standing waters.
(iii) The provision of temporary flow diversion can be easily provided for inspection and maintenance of each cell. During routine maintenance operation, water flow can be diverted to one cell and the other one is open for desilting.

If a choice has to be made between a single-cell box culvert and smaller multiple pipes, it is better to select single-cell box culvert because of the lower risk of blockage when compared with smaller size of multiple pipes. In addition, the hydraulic performance of a single-cell box culvert is better than multiple pipes system because of the larger hydraulic radius associated with the box culvert for a given cross-sectional area.

Side clearance of pipes in trenches

From the design point of view, it is preferred to minimize the width of pipe trenches because of the following reasons [29]:

(i) Higher cost of excavation is associated with wider pipe trenches.
(ii) The width of trench affects the loads on installed pipelines in consideration of embankment condition and wide trench condition. For minimum pipe trench width, the loads on pipelines can be reduced.

However, sufficient space has to be provided to allow for proper compaction. This is helpful to reduce the reaction at critical locations of pipelines under traffic and fill loads. Moreover, consideration should be given to accommodate temporary works for deep trenches where shoring has to be provided during construction.

Significance of tailwater level in culverts

The headwater level and tailwater level of culverts are important parameters in hydraulic design. The headwater level cannot be set too large, otherwise flooding upstream may occur leading to the loss of life and properties. On the other hand, the tailwater level of culverts has to comply with the following requirements [29]:

(i) For low tailwater levels at the outlet of culverts, the small depths of flow may cause significant erosion of downstream channels.
(ii) For high tailwater levels, it may cause the culvert upstream to be flowing full or even under submerged condition. As such, the headwater level is increased in order to flow through the culvert and this in turn increases the flooding risk associated with high headwater level.

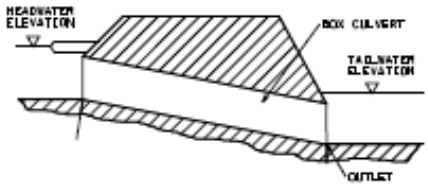

Fig. 3.6 Tailwater level in culvert.

Stilling basins

Stilling basins are usually introduced to convert supercritical flow to subcritcal flow before it reaches downstream. A typical stilling basin consists of a short length of channels located at the source of supercritical flow (e.g. end of spillway). Certain features are introduced to the basins like baffles and sills to provide resistance to the flow. As such, a hydraulic jump will form in the basin without having conducting significant amount of excavation for the stilling basin if baffles are installed [31].

*U*ncompacted bedding for concrete pipes

In the middle third of the base of precast concrete pipes, the bedding layers are recommended to be left uncompacted because it helps to reduce the reaction force at the invert of the pipes and intensifies the effect of shear forces. Moreover, the bending moment at pipe invert is increased by the compaction of bedding layer. The general rule for this region of bedding layer is that it should be firm enough for the pipes to rest on.

The sides of haunch and bedding directly under the haunch should be compacted because this will reduce the bending moment at the invert which is the critical failure location for pipes. The compacted haunch helps to resist the pipe load and maintain level and alignment.

Chapter 4. Geotechnical works

Bentonite slurry vs polymeric slurry

For the construction of diaphragm walls, bentonite slurry is commonly used to form a filter cake on walls of trenches to support earth pressure. The use of bentonite solely is based on its thixotrophic gel viscosity to provide support.

Though the cost of polymer is generally more expensive than bentonite, the use of polymer is increasing because polymer is generally infinitely re-usable and very small amount of polymer is normally required for construction works. The disposal cost of bentonite is quite high while the disposal of polymer can be readily conducted by adding agglomerator.

Bleeding test for grout – an essential requirement?

Bleeding is a form of segregation in which a layer of water migrates to the surface of the grout during the initial stage of cement hydration process. Later on, some of the floating water is re-absorbed into the grout due to further hydration reactions. Even without the problem of bleeding, there is a total reduction of volume of grout after hydration action when compared with the total initial individual volume of cement and reacted water. Bleeding tests should be carried out for grout because of the following reasons [22]:

(i) During bleeding, the upflow of water from grout mixture leads to the formation of channel paths inside the grout mix. These channels act as potential paths for aggressive materials to pass through as these channels would not be closed during further hydration of the grout.
(ii) The loss in volume by bleeding generates voids inside the grout mix which affects the properties and performance of the grout. Moreover, it increases the chance of corrosion of steel elements protected by the grout. (e.g. tendons)

(iii)In bleeding test, there is a usual requirement of total re-absorption of water after 24 hours of grout mixing because for some cold countries, this layer of water may cause severe freezing problem leading to frost damage.

Reference is made to P. L. J. Domone and S. A. Jefferis [22].

*C*ore-barrel samplers: single tube sampler vs double tube sampler vs triple tube sampler

Core barrel samplers are originally designed to sample rock. In single tube sampler, the core barrel of the sampler rotates and this poses the possibility of disturbing the sample by shearing the sample along certain weak planes. Moreover, the cored samples are subjected to erosion and disturbance by the drilling fluid.

For double tube samplers, the tube samplers do not rotate with the core barrels and the samplers are not protected against the drilling fluid. The logging of samples presents difficulty for highly fractured rock. The triple core barrel basically consists of a double core barrel sampler including an addition of a stationary liner which is intended to protect the cored samples during extraction. Therefore the quality sample obtained from triple core barrel is the best among the three types of barrels mentioned above.

*C*ontinuous Piezocone Penetration Test

Continuous piezocone penetration test basically consists of standard cone penetration test and a measurement of pore water pressure. Three main parameters, namely sleeve friction, tip resistance and pore water pressure measurement are measured under this test.

Pore water pressure generated in the soils during penetration of the cone is measured. An electrical transducer located inside the piezocone behind saturated filter is used for the measurement. By analyzing the results of pore pressure with depth, the stratigraphy of fine-gained soils with different layers is obtained readily.

*D*iaphragm wall – maintenance of excess slurry head

For the construction of diaphragm walls adjacent to buildings, previous experience showed that excess slurry head above groundwater level had to be maintained to limit the ground settlements during the construction of diaphragm walls. In fact, the excess slurry head can be achieved by the following methods. The first one is to construct a ring of well points to lower the piezometric level to achieve a higher excess slurry head in diaphragm walls. Alternatively, guide walls may be raised above ground level to accommodate the slurry column.

*D*irection of gunning in shotcreting

During the construction of shotcrete, it is aimed at gunning the full thickness in one single operation and this helps to reduce the occurrence of possible delamination and formation of planes of weakness. Moreover, the nozzles should be held about 0.6m to 1.8m from the surface [2] and normal to the receiving surface. The reason of gunning perpendicular to the receiving surface is to avoid the possible rebound and rolling resulting from gunning at an angle deviated from the perpendicular. The rolled shotcrete creates a non-uniform surface which serves to trap overspray and shotcrete resulting from the rebounding action. This is undesirable because of the wastage of materials and the generation of uneven and rough surface.

*F*unction of mortar in brick walls

A typical brick wall structure normally contains the following components:

(i) a coping on top of the brick wall to protect it from weather;
(ii) a firm foundation to support the loads on the brick wall; and
(iii) a damp course near the base of the brick wall to avoid the occurrence of rising damp from the ground.

Bricks are bedded on mortar which serves the following purposes [66]:

(i) bond the bricks as a single unit to help resist lateral loads;
(ii) render the brick wall weatherproof and waterproof; and
(iii)provide even beds to enhance uniform distribution of loads.

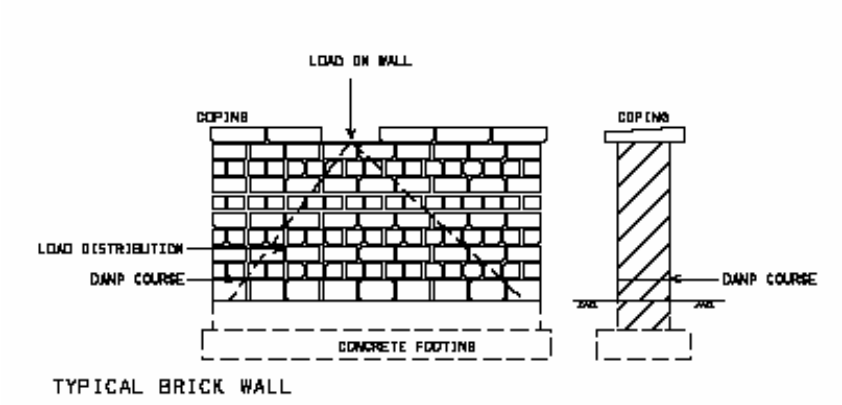

Fig. 4.1 Brick wall.

*F*ormation of frost heave

In the past, it was believed that the formation of frost heave was related to the volumetric expansion of soil water which changed from liquid state to solid state. However, the increase of volume of changes in states for water at zero degree Celsius is only about 9% and the observed heaving is far more than this quantum.

In fact, the mechanism of frost heave is best explained by the formation of ice lenses [52]. In cold weather, ice lenses develop in the freezing zone in soils where there is an adequate supply of soil water. Soil particles are surrounded by a film of water which separates the soil particles from ice lenses. The moisture adhered to soil particles gets absorbed to the ice lenses on top of the soils and in turn water is obtained from other soil pores to replenish the loss of water to ice lenses. This process continues and results in pushing up of soils on top of the lenses and subsequently the formation of frost heave.

*F*unctions of diaphragm walls

The functions of diaphragm walls are as follows:

(i) It is designed to retain soils during the construction of underground structures.
(ii) It helps to control the movement of ground during construction.
(iii) It is intended to take up high vertical loads from aboveground structures during construction (e.g. top-down approach). In addition, during the servicing of the completed structures, the diaphragm walls, internal piles and basement raft act together as a single unit to perform as piled raft.

*G*ranular fill or rock fill essential at the base of concrete retaining walls?

It is not uncommon that granular fill layers and rockfill layers are placed beneath the bottom of concrete retaining walls. The purpose of such provision is to spread the loading in view of insufficient bearing capacity of foundation material to sustain the loads of retaining walls. Upon placing of granular fill layers and rockfill layers, the same imposed loads are supported by a larger area of founding material and hence the stress exerted by loads is reduced accordingly.

Layers of granular fill and rockfill materials are not standard details of concrete retaining wall. If we are fully satisfied that the founding material could support the loads arising from retaining walls, it is not necessary to provide these layers of granular fill and rockfill materials.

"*G*rout curtain" around excavation

When excavation work is carried out in grounds with highly permeable soils, other than the installation of well points to lower down the groundwater table, consideration may be given to the injection of grout to the soils [60]. The purpose of the injection of grout is to fill the pore spaces and cavities of soils with grout and to reduce the permeability of soils. The method of grouting is effective in coarse soils but not for

sands. In essence, "grout curtain" is constructed around the excavation by installation of several rows of injection holes for grouting.

*K*icker of reinforced concrete cantilever retaining walls located at the position of largest moment and shear force – why?

Normally for reinforced concrete cantilever retaining walls, there is a 75mm kicker at the junction wall stem and base slab to facilitate the fixing of formwork for concreting of wall stems. If a higher kicker (i.e. more than 75mm height) is provided instead, during the concreting of base slab the hydraulic pressure built up at kicker of fresh concrete cause great problem in forming a uniform and level base slab.

Despite the fact that the position of kicker in a cantilever retaining wall is the place of largest flexure and shear, there is no option left but to provide the kicker at this position.

*L*oading and unloading cycles for soil nails

In carrying out pull-out tests for soil nails, it normally requires the loading and unloading of soil nails of several cycles up to 80% of ultimate tensile strength of soil nails. The principal function of soil nail tests is to verify the design assumptions on the bond strength between soil and grout which is likely to exceed the design values based on past experience. In addition, the ultimate bond strength between soil and grout can be determined and this information is helpful as a reference for future design.

Then someone may query the purpose of conducting load/unloading cycles of soil nails as it does not provide information on the above two main purposes of soil nails. In fact, loading and unloading soil nails can provide other important information on their elastic and plastic deformation behaviour. However, as stress levels in soil nails are normally low, the knowledge on elastic and plastic performance may not be of significant value. On the other hand, the creep and slippage performance of soils nails can also be obtained which may be useful for some soils.

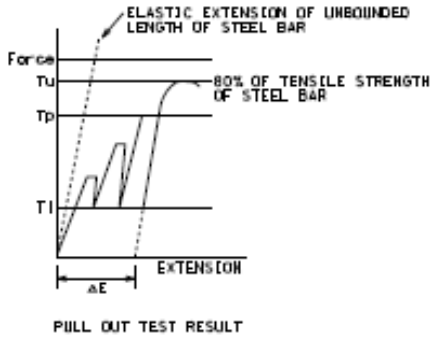

Fig. 4.2 Typical pull-out test result.

*L*andslides induced by rainfall

After rainfall, groundwater pressure is built up and this elevates the ground water table. The water inside the pores of soil reduces the effective stress of soils. Since shear strength of soils is represented by the following relations:

Shear strength = cohesion + effective stress x tanΦ where Φ is the friction angle of soils

Hence, the presence of water causes a reduction of shear strength of soils and this may lead to landslide. On the other hand, the rainfall creates immediate instability by causing erosion of slop surface and results in shallow slope failure by infiltration. In addition, the rain may penetrate slope surface openings and forms flow paths. As a result, this may weaken the ground.

*P*iston samplers

In sampling clays or silts, Piston sampler is lowered into boreholes and the piston is locked at the bottom of the sampler. This prevents debris from entering the tube prior to sampling. After reaching the sampling depth, the piston is unlocked so that the piston stays on top of the sample going into the tube. Prior to the withdrawal of the sampler, the

piston is locked to prevent the downward movement and the vacuum generated during the movement of the piston from the sampler's end aids in retaining the samples recovered. As such, sample recovery is increased by using Piston samplers.

*P*osition of shear keys under retaining walls

The installation of shears keys helps to increase the sliding resistance of retaining walls without the necessity to widen the their base. The effect of shears keys enhances the deepening of the soil failure plane locally at the keys. The increased sliding resistance comes from the difference between the passive and active forces at the sides of the keys. In case weak soils are encountered at the base level of shear keys, the failure planes along the base of retaining walls due to sliding may be shifted downwards to the base level of the keys.

Shear keys are normally designed not to be placed at the front of the retaining wall footing base because of the possible removal of soils by excavation and consequently the lateral resistance of soils can hardly be mobilized for proper functioning of the shear keys [30]. For shear keys located at the back of footings, it poses a potential advantage that higher passive pressures can be mobilized owing to the higher vertical pressure on top of the passive soils.

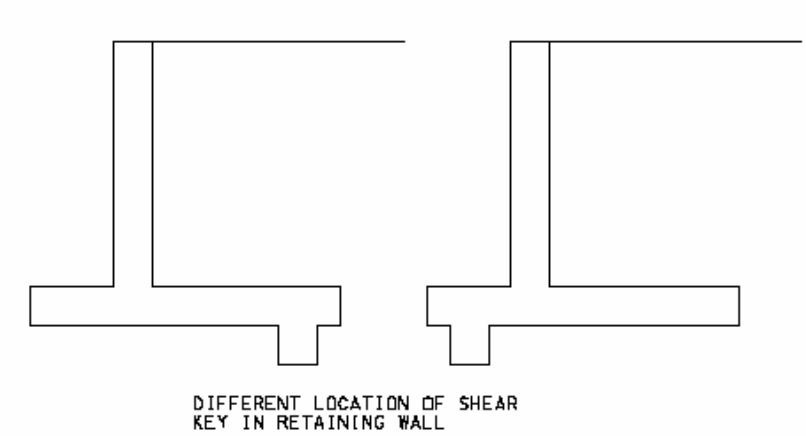

Fig. 4.3 Different locations of shear key in retaining wall.

*P*ressure distribution under rigid and flexible footings

For thick and rigid footings, the pressure distribution under the footings is normally assumed to be linear. If uniform and symmetrical loadings are exerted on the footings, the bearing pressure is uniformly distributed. However, if unsymmetrical loads are encountered, then a trapezoidal shape of bearing reaction would result.

For flexible footings on weak and compressible soils, the bearing pressures under footing would not be linear. As such, a detailed investigation of soil pressures is required in order to determine the bending moment and shear forces of the structure.

*R*ock reinforcement – how it works?

For rocks with widespread fractures, individual blocks resulting from these fractures may fall out and as a result slope failure may occur. Rock reinforcement (e.g. rock dowels, bolts or anchors) is installed to bolt through the discontinuities in rock to enhance the rock to behave as a single unit. With the bolting across block interfaces, the stresses would be altered within the rock mass. For untensioned rock dowels, they may be subjected to tensile forces arising from rock movement. Other than the provision of rock reinforcement, shotcreting is another method to reinforce the rock. It functions by griping the rock together and maintaining the small blocks which hold the large blocks in position [37].

*R*owe cell vs Oedometer apparatus

The advantages of using Rowe cell over oedometer apparatus are:

(i) It possesses the control facilities for drainage and for the measurement of pore water pressure.
(ii) It is capable of testing larger diameter soil samples. Hence, more reliable data can be provided by using Rowe's cell because of the relatively smaller effect of structural viscosity in larger specimens.
(iii) Rowe cell uses hydraulic loading system which is less susceptible

to the effect of vibration than oedometer apparatus.

*S*and cone (replacement) test – suitable for all soils?

Sand cone (replacement) test is normally carried out to determine the in-situ and compacted density of soils. This testing method is not suitable for granular soils with high void ratio because they contain large voids and openings which provide an access for sand to enter these holes during the test. Moreover, soils under testing should have sufficient cohesion so as to maintain the stability of the sides of excavation during the excavation step in sand cone (replacement) test. In addition, organic or highly plastic soils are also considered not suitable for this test because they tend to deform readily during the excavation of holes and they may be too soft to resist the stress arising from excavation and from placing the apparatus on the soils.

*W*ater control for sheet pile walls

Ground water flow into excavations constructed by sheet pile walls should be minimized in order to save the cost of the provision of pumping systems or well points to lower the water table inside the excavation. In case a layer of impermeable material like clay is located slightly below the excavation, it may be desirable to drive the sheet piles further into this layer and the cost of further driving may be less than the cost of the provision of continuous pumping in the excavation. On the other hand, if there is no impermeable layer beneath the excavation, engineers may consider driving the sheet piles further so as to increase the flow path of groundwater into the excavation and this helps to reduce the amount of water flow into the excavation. Similarly, a cost benefit analysis has to be carried out to compare the extra cost of driving further the sheet piles with the reduced pumping costs.

*W*ires in gabion walls

Gabions are wire mesh boxes which are filled with stones and they are

placed in an orderly pattern to act as a single gravity retaining wall. Lacing wires or meshes are designed to hold the gabion boxes together. Most of the wires are zinc-coated or PVC coated to prevent the steel wire from corrosion. Moreover, it is common that the wires are fabricated in hexagonal patterns with doubly twisted joints to avoid the whole gabion mesh from disentanglement in case a wire accidentally breaks. Owing to the nature of gabion filling materials, they are very permeable to water. They have particular application in locations where free water drainage has to be provided. Moreover, gabions are capable of accommodating larger total and differential settlements than normal retaining wall types so that they are commonly found in locations where the founding material is poor.

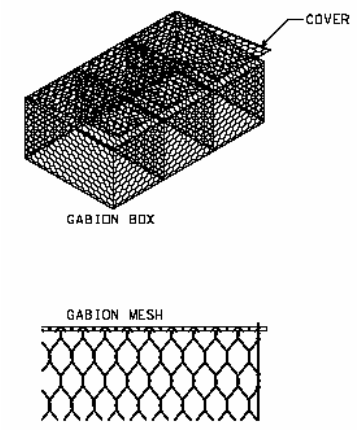

Fig. 4.4 Wires of gabion walls.

Chapter 5. Marine Works

*D*irection of approaching velocities of ships during berthing

One of the major effects of angle of approaching velocities of ships is its influence of the energy to be absorbed by the fender system. Consider several ships berth on the same pier at the same speed but with different angle of approach, though their kinetic energies are the same, the amount of energy absorbed by fender differs. The amount of energy absorbed by fender is [19]:

$$W = \frac{0.5mv^2(k^2 + r^2\cos^2\Phi)}{(k^2 + r^2)}$$

where W= energy absorbed by the fender
m= mass of the ship
v=velocity of the ship
k= radius of gyration of the ship
r= distance of centre of gravity of the ship to the point of contact of the fender
Φ=direction of velocity

Hence, when the direction of approaching velocity of a ship is normal to the fender system (i.e. $\Phi=90^{\circ}$), the amount of energy absorbed is smaller when compared with that of a ship whose velocity is tangential to the shoreline.

*E*nergy absorbed in heeling during vessel berthing

When a vessel berths on a fender system at a pier, the point of contact of the berthing ship may be above or below the centre of gravity of the ship. During the berthing operation, some kinetic energy is dissipated in work done to heel the ship i.e. the work done to bring the ship an angle of heel. This energy is normally a small fraction of total berthing energy and therefore it is normally not considered in design. However, designers should pay attention to the possible hitting of the berthing

structure by the vessels in case the contact point is well above water level [19].

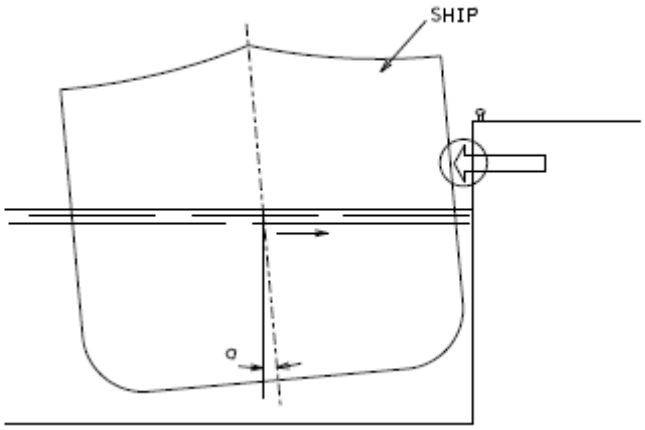

Fig. 5.1 Heeling of a vessel.

*F*actors determining the stability of a single armour unit

There are mainly three main factors which govern the stability of a armour unit, namely, gravity, intertangling and squeezing. Obviously, it is beyond doubt that the ability of the armour unit to stay in place should be closely related to gravity force. On the other hand, the geometry of the armour unit also affects its stability. For instance, with the difference in ability to intertangle, their resistance to pulling out by waves varies. Furthermore, squeezing forces by gravity also affects the stability of the armour unit which is dependent on frictional forces in all directions.

*F*unction of reinforced concrete infill in marine piling system of steel tubular pile with reinforced concrete infill

Reinforced concrete is designed to fill the void space inside the steel tubular piles from pile cap to a certain distance below seabed. As mentioned earlier, steel tubular piles above seabed level is assumed in

design to be completely corroded when approaching the end of design life. As such, loads from pile caps are transferred directly to reinforced concrete infill instead of steel tubular piles. The load transfer path below seabed level is as follows: loads from reinforced concrete infill are transferred to steel tubular piles through frictional forces between reinforced concrete infill and steel piles. Therefore, mobilization of frictional forces between reinforced concrete infill and steel piles is essential to ensure that the piling system functions properly.

*H*udson's formula vs Van der Meer formula

Hudson's formula is commonly adopted in preliminary design to obtain rough initial estimate of rock size. The formula is derived from the results of regular wave tests. However, this formula does not take into account the following elements which Van der Meer formula does: wave period, damage level, permeability of structure and storm duration. Moreover, Hudson's formula deals with the use of regular waves only.

Compared with Hudson's formula, Van der Meer formula is more complicated and it is derived from results of a series of physical model tests. They include the consideration of wave period, storm duration, clearly-defined damage level and permeability of structure. The choice of the appropriate formula is dependent on the design purpose (i.e. preliminary design or detailed design).

*I*mmersed tube method for underwater crossings

The immersed tube method for underwater crossing involves the following basic construction steps:

(i) Prefabricating long tunnel units (steel shell or concrete) in a dry-dock or shipyard
(ii) Floating and towing the units with removable bulkhead to the site
(iii) Immerse the units in a pre-dredged trench
(iv) Connect the units one by one
(v) Covering the completed tunnel with backfill

Steel immersed tunnel is sometimes adopted because of the ease of fabrication and its relative lightness. Moreover, shorter construction time is required when compared with concrete immersed tubes.

*I*n reclamation involving large volumes of fill and tight programme, shall engineers use marine fill or mud extracted from land borrow area as filling material?

There are two advantages of adopting marine fill over mud extracted from land borrow area:

(a) In some land borrow areas, it involves breaking up of rock to suitable sizes for reclamation and the production rate is not high. With modern equipment for dredging and placing marine fill, the filling rate is much higher.
(b) The cost incurred for breaking up of rock to suitable sizes for reclamation is very expensive while the cost of hydraulic filling with marine fill is lower.

*R*easons of common occurrence of "inadequate pile founding level" in piles of piers

The most severe load on piers generally is the horizontal load due to berthing and mooring of large vessels. The design of piers is taken as an example to illustrate the importance of adequate pile founding level. Since the widths of open berth piers are relatively small so that they provide a short lever arm to counteract the moment induced by berthing loads. Moreover, the dead load of open berth piers are normally quite light and therefore the resisting moment provided by the dead load of pier structures may not be sufficient to counteract the moment generated by berthing loads. To aid in providing adequate resistance to the overturning moment by the berthing load, the soil resistance above bedrock contributes to the stabilizing moment. For commonly adopted marine piling type, i.e. driven steel tubular piles with reinforced concrete infill, driven piles can at most be founded on top of rockhead surface. In case the rockhead level is shallow (e.g.

near shoreline), the little soil cover may result in inadequate lateral resistance to the berthing load.

Silt curtain touching seabed

Silt curtains are impermeable vertical barriers extending from the seawater surface to their designed depths. The curtains are held in a vertical position by the carrier float on their top and a curtain weight at their bottom. A tension cable is designed at the carrier float to resist stresses incurred by currents. Moreover, the silt curtains are anchored to the seabed to hold them in the designed configuration.

In essence, the depth of silt curtains should not be so long and touch the seabed because the bottom segment of the silt curtains would be trapped inside the newly accumulated sediment, thus resulting in the sinking of the curtain. It is difficult to remove these sunken curtains. Moreover, reversal tidal and current actions may cause movement of bottom region of curtains which stir up the settled suspensions and create additional turbidity.

Shoes of prefabricated drains

Shoes are normally installed in prefabricated drains for the following reasons [35]:

(i) It avoids the entry of soils into the mandrel by sealing it during the installation of drains.
(ii) It performs like an anchor to retain the drains at the designed depth and to stop the drains from being pulled out during the withdrawn of mandrels after driving the mandrels into ground.

However, the inclusion of shoes in prefabricated drains tends to aggravate the problem of smear effect because the shoes are usually larger in size than mandrels.

Soil plug in marine piling system of steel tubular pile with reinforced concrete infill

During initial driving process, open-ended steel piles are driven through the soils at their bases. However, shaft friction will gradually develop between the steel piles and soils inside piles at some time after pile driving. The hitting action of driving hammers induces forces to the soil and later it comes to a stage when the inertial forces of inside soils, together with the internal frictional forces exceeds the bearing capacity of soils at pile toes. Consequently, the soil plug formed is brought down by the piles.

It is practically possible to excavate all soils inside steel tubular piles and replace them completely by reinforced concrete. However, as engineers strive to produce economical design the extra cost associated with excavation of soil plug and filling of concrete could be saved in case the soil plug remains in position. Moreover, from the technical point of view it is considered unnecessary to remove the soil plugs because it serves to provide a platform for the placing of on-top infill concrete on one hand and to fill the void space below the infill concrete on the other hand. In addition, the soil plug is considered to be sufficiently compacted by pile driving action and is deemed to be stable during the design life of the piling system.

The Morison equation vs diffraction analysis in determining wave force on piles

The choice between the Morison's equation and diffraction analysis in determining the wave forces on piles depends on the ratio between the diameters of piles to wavelength. If the ratio between the diameter of piles to wavelength is less than 0.2, the Morison equation is usually recommended. The reason behind this is that the effect of viscosity and separation is significant below this ratio. On the contrary, if the ratio between the diameter of piles to wavelength exceeds 0.2, the waves are scattered with negligible occurrence of separation. As such, diffraction analysis is adopted to calculate the wave forces on piles.

*V*ibrocoring in marine ground investigation

If only shallow marine ground geotechnical information is required for design purpose, vibrocoring is inevitably a good choice for sampling disturbed samples. In vibrocoring, a core barrel and an inner liner usually of 100mm diameter and 6m long are vibrated into the seabed. Since the installation of vibrocoring involves the vibration of barrels, there is considerable disturbance of recovered samples. Vibrocoring has the merit of the fast speed of sample recovery (e.g. up to 14 cores can be obtained in one day). Moreover, the cost of vibrocoring operation is low when compared with other viable marine geotechnical investigation options.

*Z*ones of smear around vertical drains

Smear zones are generated during the installation of vertical drains in which the zone of soils surrounding the band drains are disturbed. Soils in the smear zones are remoulded during the installation process and the effectiveness of band drains is reduced. For instance, the compressibility of surrounding soils is increased and this brings about the reduction of their permeability. In essence, with the reduced permeability of soils around band drains, it takes longer time to complete the consolidation process.

To prevent the formation of smear zones, the raising and lowering of mandrel during drain installation should be minimized. Moreover, soil disturbance can be controlled by avoiding the use of vibratory hammers which serve to drive the drains into the ground [35].

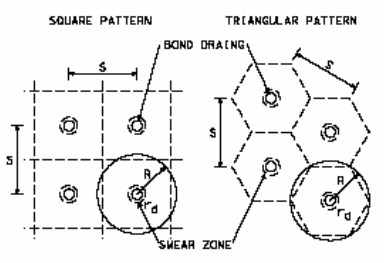

Fig. 5.2 Smear zones in band drain.

Chapter 6. Piles and Foundation

A pipe or groups of bars be adopted as load carrying element of min-piles?

The design of mini-piles somehow differs from other traditional pile types. For instance, the design of most common pile types is controlled by the external carrying capacity. However, owing to the small cross sectional area, the design of mini-piles is limited by internal carrying capacity. Hence, the choice of suitable load carrying element is of paramount importance in the design of mini-piles.

For steel pipes used as load carrying element, it is of circular cross section with a high radius of gyration. Moreover, it possesses a constant section of modulus in all directions, it serves the properties of excellent column. Bars are suitable when pure axial loading is required in confined situation.

*A*rrangement of piles in a pile cap to reduce bending moment induced in piles

Consider that piles are designed to intersect at a single common point in a pile cap. The resultant reactions would pass through the point of intersection in the pile cap. This type of arrangement does not involve any bending moment induced if the horizontal loads pass through this point. However, in real life situation, the piling system is expected to resist a combination of vertical loads, horizontal loads and bending moment. To counteract bending moment, the pile cap about the point of intersection is rotated so that significant amount of bending moment is induced in piles and pure axial forces in piles can hardly generate a counteracting moment based on one single intersection point [53].

However, if the piles are arranged in such a way that there are at least two separated points of intersection in the pile cap, the amount of flexural stresses induced in piles is significantly reduced.

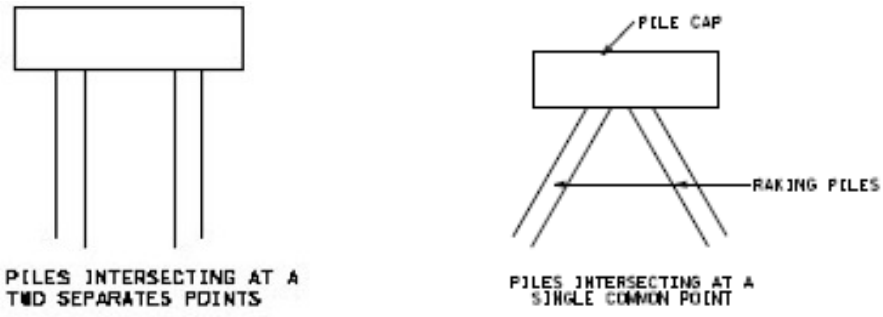

Fig. 6.1 Different arrangement of piles in pile cap.

*A*pplication of bitumen to driven piles

In a certain region of H-piles subjected to ground water table fluctuation, painting is sometimes applied on the surface of H-piles because the rise and fall of water table contribute to the corrosion of H-piles. On the other hand, to reduce the effect of additional loads brought about by negative skin friction, bitumen is applied on the pile surface corresponding to the region of soils that has negative skin friction. However, bitumen should not be applied to the whole section of H-piles because it will be unable to derive the designed frictional reaction from soils. Actually, some engineers have reservation of the effectiveness of bitumen slipcoat because the bitumen may get removed during pile driving.

*A*ddition of water to bored piles

In water bearing ground, some water head (about 1 m) above the existing ground water table is maintained to stabilize the bore during excavation below casings by pumping water to the pile bore. This balanced head condition is created to minimize the possible drawdown of surrounding water table which may affect the stability of nearby structures. Moreover, this helps to limit the possible inflow of water by piping from the base of pile bore.

*B*ase fixity

When structures like portal frames are connected to the base foundation, engineers have to decide the degree of fixity for the connection. In general, the two common design options are pinned bases and fixed bases. Pinned bases have the advantage that the design of foundation is made simple so that some cost savings may result. However, fixed bases design provides additional rigidity and stiffening to the structures and the stability of the structures can be enhanced. Therefore, the use of fixed bases helps to improve the structural performance of the structures [41].

*C*ompaction to freshly placed concrete piles

In normal practice, reliance is placed on the self-compaction of specially designed concrete mixes to achieve adequate compaction. The use of vibrating devices like poker vibrators is seldom adopted for the compaction of concrete piles. In fact, other than the consideration of the impracticality in using vibrating device in long piles, there is serious concern about the possible occurrence of aggregate interlock which poses difficulty during casing extraction [64]. In the worst scenarios, the temporary casings together with reinforcement cages are extracted during the lifting up of pile casings. This is another reason which accounts for not using vibrating machines for piles with casing extraction.

*D*esign approach for the spacing of min-piles

For close spacing of min-piles, it would provide substantial cost savings with the reduction of pile cap size. However, close spacing of piles implies the problem of group effect which tends to reduce the load carrying capacity of each pile member. Notwithstanding this, there is well established rule which govern the minimum spacing of piles, i.e. for friction piles like mini-piles, the centre-to-centre spacing should not be less than the perimeter of the pile.

*E*dge piles take up more loads than central piles in rigid cap

Due to the effect of interaction of individual piles, the central piles tend to settle more than the edge piles when the pile cap is under a uniform load. For the pile cap to be rigid, the local deformation of central piles would not occur. Instead, the stiff pile cap would transfer the loads from the central piles and redistribute them to the outer piles. Therefore, raking piles at the edge take up a higher fraction of the total loads and are subjected to higher axial and bending loads in case the pile cap is stiff. In the extreme case, the side piles may take up as much as about two to three times the loads in the central piles and this may lead to the failure of these raking edge piles.

There are several choices regarding the design to tackle the uneven distribution of loads. The first one involves the lengthening of side piles to stabilize the piles under high loads. However, the increased length of outer piles tends to attract more loads and this seems not to be a good solution. The other way out is to lengthen the central piles aiming at getting more loads and this evens out the load distribution among the piles [26].

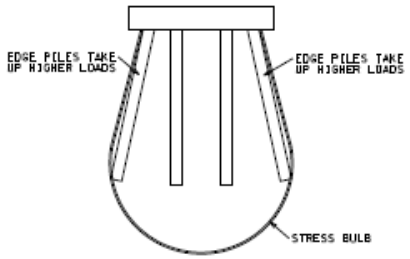

Fig. 6.2 Stress bulb effect on load distribution in piles.

*E*ffect of pile installation method to load carrying capacity of piles

The construction of piles by driving method causes an increase in density of the surrounding soils. Hence, for loose soils this results in improved compaction of soils between the piles. The sum of the capacities of all piles as a whole is generally greater than the sum of individual pile capacities provided that the effect of pile spacing is not taken into account. However, for bored piles the boring operation induces considerable stress relief and this causes a substantial

reduction in shear strength of soils.

*F*ree- fall concrete placement in bored piles

Based on the research by STS Consultants Ltd. [57], it was found that concrete placed by free falling below 120 feet would not suffer from the problem of segregation and the strength of concrete would not be detrimentally impaired provided that the piles' bore and base are dry and free of debris. Moreover, it is presumed in the past that during free falling of fresh concrete into the pile bores the hitting of falling concrete in the reinforcement cage causes segregation. However, in accordance with the experimental results of STS Consultants Ltd. [57], the striking of reinforcement cage by fresh concrete does not have significant effect on the strength of concrete

In addition, for long bored piles, it is impractical to conduct vibration to concrete. For concrete placed by free falling method, the impact action arising from free falling is assumed to induce adequate vibration. On the other hand, concrete placed by tremie method appears to be lack of vibration and this may affect the strength and integrity of concrete. The research results showed that the strength of vibrated concrete was slightly higher than unvibrated concrete. Vibration proved to have added advantage to concrete strength but not essential to achieve the design pile strength.

*F*alse set in pile driving

For pile driving in certain soils like dense silt and weathered rock, the occurrence of false set phenomenon is not uncommon. During the driving process, negative pore water pressure is developed and the driven piles appear to have sufficient capacity during pile driving as the built-up of negative pore water pressure leads to an apparent temporary increase in driving resistance and strength. However, some time after the pile driving, the dissipation of this negative pore water pressure would reduce the bearing strength in resisting the design loads. Sometimes, the presence of cracks along pile sections may bring about the problem of false set by the dampening effect of stress waves

by these cracks. To avoid the problem of false set, a certain percentage of constructed piles should be chosen to perform re-driving to check for the false set phenomenon [26].

*F*ixed vs pinned connection between piles and pile caps

The type of connection between piles and pile caps affects the load carrying capacity of pile groups. The fixity of pile head into pile cap, instead of pinning into pile cap, enhances higher lateral stiffness of the pile groups. For instance, for the same deflections, a cap with fixed connected piles can sustain far more loads than that of pinned connected piles. To satisfy the criterion of fixed connection, the minimum embedded length of piles into pile caps should be at least two times the diameter of piles.

Moreover, the fixed connection of piles at pile caps allows significant bending moment to be transmitted through the connections when compared with pinned connections.

*F*orty-five degree spread rule for driven piles

For driven piles the length of piles driven into the ground is usually based on dynamic driving formula like Hiley's formula. In certain ground (e.g. chalk) the length of piles driven by adopting pile-driving formulas may be far more than adequate because the soil strength may increase with time. On the contrary, in silty soils the phenomenon of false set may appear and the piles give a false impression of obtaining sufficient bearing resistance from the ground. Hence, the pile's capacity should be verified and checked later by loading test.

In case driven piles are founded on different depths below ground, 45-degree spread rule is usually applied to check their load carrying capacities. The base bearing loads of higher driven piles are assumed to spread at 45 degrees from their bases and checking is made if the loads from higher piles would influence or get transmitted to deeper ones [30].

*F*unctions of different reinforcement in a typical pile cap

Loads from columns transferring to pile cap induce tensile forces at the bottom of the cap. For instance, by using truss analogy to analyze a pile cap sitting on two piles with a column at the centre of the pile cap, the tensile force at the bottom is proportional to the pile spacing and is inversely proportional to depth of pile cap. The bottom reinforcement is designed to resist the tensile stressed generated from loads in columns.

Side reinforcement may not be necessary in pile cap [16]. In fact, the primary aim of the side reinforcement is to control cracking. However, as most pile caps are hidden from view and it is considered not necessary to provide side reinforcement to pile caps based on aesthetic reason.

Sometimes, reinforcement may be designed at the top of pile caps which serve as compression reinforcement. This type of reinforcement is required in case there is a limitation on the depth of pile caps. Similarly shear reinforcement is introduced to the pile caps in case there is a restriction to the depth of pile caps.

*H*ammer efficiency vs coefficient of restitution

Hammer efficiency refers to the ratio of kinetic energy of the hammer to the rated energy (or potential energy). In essence, it is undoubtedly that certain energy losses are induced by the hammer itself prior to the actual impact on the driven piles. For instance, these losses may include the misalignment of the hammer, energy losses due to guiding friction, inaccurate dropping height etc…

Coefficient of restitution refers to a value indicating the strain energy during collision regained after the bodies reverting back to their original shapes. If the coefficient of restitution is equal to unity, it means that the collision is elastic and all energy has been returned after the impact action. Hence, this is an index showing the degree the impact action in terms of elasticity.

In mathematical forms,

coefficient of restitution = $-(v_1-v_2)/(u_1-u_2)$
where u=initial velocity and v=final velocity after impact

*H*oles in steel plates connecting to H-piles

There are two kinds of holes present in the steel plate connected to H-piles in the pile cap. The first kind of holes is designed to be filled with welding for better connection with H-piles. The second kind of holes is present to facilitate concreting works of the pile caps. In fact, the void space underneath the steel plate is hardly to be accessed by concrete and these holes provide alternative paths to gain entry into these hidden void.

*M*aximum spacing of piles

One of the factors that affect the distribution of loads from the structures to each pile is the assumption of flexibility of the pile caps in design. A pile cap can be modeled as a flexible or a rigid element based on their relative stiffness. For the pile cap to be assumed as rigid the stiffness of pile cap is infinite relative to that of pile/soil system and the deformations within the cap are not considered owing to its rigidity. On the other hand, for the pile cap to be designed as flexible, internal deformations of pile cap would occur.

In some design guidelines, maximum spacing of piles is specified to limit the length between adjacent piles so that the assumption of rigid pile cap can be justified.

*N*ecessity of pile tip cover for rock-socketed H-piles

In current practice concrete cover is usually provided at the pile tips of pre-bored H-piles socketed in rock. The purpose of such arrangement is to avoid the potential occurrence of corrosion to H-piles in case concrete cover is not designed at pile tips. However, recent field and

laboratory observations had reservation of this viewpoint [45]. In case H-piles are designed to be placed directly on top of rock surface, it provides the tip resistance to limit the pile movement in the event of bond rupture between grout and H-piles. As such, some contractors may choose to tamp the H-piles by using drop hammers to ensure the H-piles are founded directly on top of rock surface. Practically speaking, it poses difficulties during the process of tamping because there is a chance of possible buckling of long H-piles when too much energy is provided to the piles.

*P*oint of virtual fixity and critical length of lateral loading for piles

Some engineers may get confused about the difference between the two terms i.e. point of virtual fixity and critical length used for piles for resisting lateral loads. For critical length of lateral loading for piles, it refers to a certain depth from the ground level where the piles behave as if it were infinitely long. As such, beyond the critical length, the change in lateral response of piles with increase in pile length will be negligible [26].

Point of virtual fixity refers to a certain dept below ground surface where the piles are fixed without movement under loads. The depth to the point of fixity is useful in assessing the buckling loads of piles. It is obvious that the depth to the point of virtual fixity should be smaller than the critical length of piles.

*P*rinciple of airlifting for cleaning pile bores

Airlifting is normally carried out prior to concreting to remove debris and clean the base of pile bores. It essentially acts as an airlift pump by using compressed air. The setup of a typical airlifting operation is as follows: a hollow tube is placed centrally inside the pile bore and a side tube is connected to the end of the tube near pile bottom for the passage of compressed air inside the tube. The upper end of the tube is linked to a discharge tank for the circulation of pumped fluid from pile base.

The efficiency of airlifting operation is dependent on the performance of air compressor. During airlifting, compressed air is piped down the tube and it returns up to the discharge tank carrying it with the fluid. It functions by imparting energy to the fluid and forces the fluid to move vertically upwards. The injected air mixes with the fluid, resulting in the formation of lower unit weight of the combined mixture when compared with surrounding fluid. This hydrostatic pressure forces the fluid/air mixture up to the discharge tanks.

*R*everse and direct circulation drill drilling in piling

For direct circulation drilling and reverse circulation drilling, the major difference in drilling method is related to the direction of movement of drilling fluid. For direct circulation drilling, the drilling fluid is circulated from the drill stem and then flows up the annulus between the outside of the drill stem and borehole wall. The drilling fluid that carries the drill cuttings flows to the surface and the subsequent settlement pits. Pumps are employed to lift the cuttings free fluid back to the drill stem.

For reverse circulation drilling, the direction of flow of drilling flow is opposite to that of direct circulation drilling. Drilling fluid flows from the annulus between the drill stem and hole wall to the drill stem. The drilling fluid is pumped to nearby sump pits where cuttings are dropped and settled.

*R*easons of using compressed air as drilling fluid

For rotary drilling in ground investigation works, drilling fluid is normally used to clear and clean the cuttings from the drilling bits and transport them to the ground surface. Moreover, it also serves to produce a cooling effect to the drilling bit. In addition, the stability of boreholes can be enhanced and the drilling fluid also produces lubricating effect to the bits.

Compressed air when used as a drilling fluid possesses several advantages. Firstly, the use of compressed air can reduce the loss of

fluid during circulation which is commonly encountered for water being used as drilling fluid. Secondly, the efficiency of air to clean drilling bits is higher than other types of drilling fluids. Thirdly, the moisture condition of in-situ soils would not be affected by air when compared with water as drilling fluid. In addition, in cold countries the occurrence of freezing of drilling water/mud can be avoided by using air. However, special attention should be taken to avoid breathing the generated dust when compressed air is employed as drilling fluid and dust suppression measures have to be properly implemented.

Stresses during pile driving

In pile driving operation, proper selection of piling hammers is essential to prevent the damage of piles. For instance, a light hammer with higher drop causes a higher impact stress than a heavy hammer with lower drop provided that they generate the same energy per blow.

During driving, the piles are continuously subjected to considerable reflected tensile stresses and compressive stresses. In case the pile sections are incorrectly aligned, the lack of straightness may induce significant bending stresses being locked in piles during pile driving. Moreover, if obstructions are encountered during pile driving, bending stresses would be induced in piles.

Shaft grouting for friction barrettes

For the construction of friction barrettes, some grout pipes are designed at the periphery of the barrettes. Within a short duration (e.g. 24 hours) of concreting of barrettes, the fresh concrete cover is cracked by injecting water. After that, shaft grouting is conducted where the grout travels along the interface between concrete and soil and compacts the surrounding soils which are loosened or disturbed during excavation. The hydraulic fracturing of surrounding soils by grout during the grouting operation generates planes of higher shear strength. The grout would penetrate and improve the strength of soils around the barrettes.

Strain compatibility in mini-piles

In designing the axial capacity of mini-piles, grout may be taken into account in the contribution of axial load capacity. However, the total load capacity of min-piles may not be equivalent to the sum of individual capacity derived from grout and from steel H-section. The reason behind this is that the vertical loads on mini-piles are shared among grout and steel sections based on their Young's modulus and areas. Basically, in order to comply with strain compatibility criterion, the steel bars and grout will deform as a whole though they possess different stiffness. A case may occur in which the sharing of loads for grout may be too high which cracks the grout section and fails the mini-piles already before the whole pile section could attain the full design load which is assumed to be the sum of individual capacities. Hence, strain compatibility has to be checked in designing the vertical capacity of min-piles [28].

Which type of pile cap transfers loads equally to piles, flexible pile cap or rigid pile cap?

Loads from columns transferring to pile cap induce tensile forces at the bottom of the cap. For instance, by using truss analogy to analyze a pile cap sitting on two piles with a column at the centre of the pile cap, the tensile force at the bottom is proportional to the pile spacing and is inversely proportional to depth of pile cap. The bottom reinforcement is designed to resist the tensile stressed generated from loads in columns. Sometimes, reinforcement may be designed at the top of pile caps which serve as compression reinforcement. This type of reinforcement is required in case there is a limitation on the depth of pile caps. Similarly shear reinforcement is introduced to the pile caps in case there is a restriction to the depth of pile caps.

Consider that loads are applied at the centre of a pile cap.

For the case of rigid pile cap, owing to the effect of interaction of individual piles, the central piles tend to settle more than the edge piles when the pile cap is under loading condition. For the pile cap to be rigid, the local deformation of central piles would not occur. Instead,

the stiff pile cap would transfer the loads from the central piles and redistribute them to the outer piles. Therefore, piles at the edge take up a higher fraction of the total loads and are subjected to higher axial and bending loads in case the pile cap is stiff. In the extreme case, the side piles may take up as much as about two to three times the loads in the central piles and this may lead to the failure of these edge piles.

For flexible pile cap, load taken up by individual piles are different because the deformation of pile cap enhances non-uniform distribution of loads among piles. The piles closer to the load tend to share more loads when compared with those which are located far away from the loads. The difference of loads induced in piles increase with the flexibility of pile cap.

Chapter 7. Roadworks

Aggregates, filler and binder in bituminous pavement

In bituminous materials, course aggregates perform the bulking action of the mixture and contributes to the stability of resulting mix. Fine aggregates form the major proportion of mortar.

Filler: it stiffens and strengthens the binder.
Binder: cements the whole mixture together and provides waterproofing.

Asphalt mix design – durability vs stability

The main objective of asphalt mix design is to achieve a mix with economical blending of aggregates with asphalt to achieve the following [61]:

(i) workability to facilitate easy placement of bituminous materials without experiencing segregation;
(ii) sufficient stability so that under traffic loads the pavement will not undergo distortion and displacement;
(iii) durability by having sufficient asphalt;
(iv) sufficient air voids

In asphalt mix design, high durability is usually obtained at the expense of low stability. Hence, a balance has to be stricken between the durability and stability requirements.

Avoidance of designing acute angle of concrete pavement

The stress induced in acute angle corners of concrete pavement is far much higher than that in right-angle corners of the pavement. For instance, concrete pavement corner of acute angle of 70^o induces stresses about 50% more than the stress induced by an angle of 90^o. As

a result, corners of concrete pavement should not be designed with acute angles to avoid corner cracking. If it is necessary to adopt acute angles for concrete pavement, special reinforcement has to be provided to strengthen these corners [55].

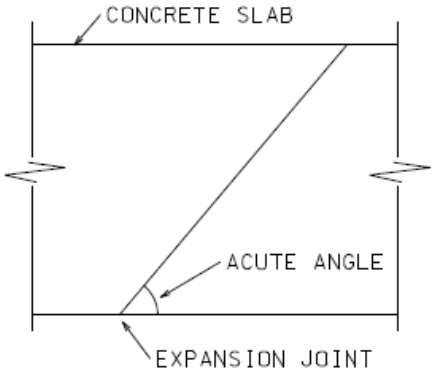

Fig. 7.1 Acute angle of concrete pavement.

*B*itumen emulsions – difference between anionic emulsions and cationic emulsions

Bitumen emulsions consist of particles of bitumen dispersed in water by using emulsifying agent. When the emulsion breaks, it represents a change from a liquid to a coherent film with bitumen particles coagulating together. The sign of breaking is the change of colour from brown to black as the colour of emulsion and bitumen is brown and black respectively.

There are in common two broad types of emulsions, namely anionic emulsions and cationic emulsions. The breaking of anionic emulsions is dependent on the evaporation of water from bitumen emulsion. As such, it poses difficulty in wet weather condition. However, for cationic emulsions, instead of relying on the evaporation of water the breaking is achieved by chemical coagulation. Hence, cationic emulsions are particularly useful in wet weather conditions [66].

*B*ituminous surfacing over concrete structures

The use of bituminous surfacing over concrete structures (e.g. existing concrete roads) is widespread to improve the skid-resistance and the general appearance of roads on one hand, and to avoid the pre-mature failure of concrete surface by frost spalling in cold countries on the other hand.

In designing the bituminous surfacing over concrete, there are several areas to which engineers should pay attention. Firstly, the laying of thin bituminous material over the joints or existing cracks of concrete structure would lead to reflective cracking because the thermal movement of concrete induces swift formation of cracks in bituminous surfacing. Past research demonstrated that with the adoption of minimum thickness of 100mm bituminous surfacing the occurrence of reflective cracks would be delayed when compared with the use of thinner surfacing. Secondly, sufficient adhesion between concrete and bituminous surfacing has to be achieved. Therefore, it is recommended to apply a layer of tack coat on the concrete surface to promote bonding.

*C*orner reinforcement for concrete pavement

Consider a panel of concrete slab without any load transferring devices at it edges. When the concrete panel is subjected to traffic loads, the maximum stress induced in the concrete panel is at its four corners. Other than panel corners, the next significant stress induced in concrete slab is its four edges.

To avoid the structural failure of concrete pavement, one can locally increase the thickness of corners and edges to reduce the induced stresses. However, such local thickenings also increase temperature stresses. Moreover, the construction of non-uniform concrete pavement is not convenient from practical point of view. The other way out is to use load transfer devices like dowel bars at the edges of concrete panels. However, in situation where the designed thickness of concrete pavement is small which renders the provision of dowel bars not practical, special design of corner reinforcement has to be

considered [21].

*C*ompacted thickness of bituminous pavement

The choice of compacted thickness is closely related to the nominal maximum size of aggregates of bituminous materials. Based on the recommendation by Dr. Robert N. Hunter [38], the rule of thumb is that the compacted layer thickness should exceed 2.5 times the maximum size of aggregate. If the layer thickness is less than 1.5 times the nominal maximum size of aggregates, the mechanical properties of bituminous material is impaired by the possible crushing of larger sizes of aggregates. Hence, controlled thickness of compaction of bituminous material should be clearly stated in works specification [38].

*C*oncrete road enhances fuel saving when compared with bituminous road

Concrete road belongs to rigid pavement and they do not deflect under traffic loads. On the contrary, bituminous pavement deflects when subjected to vehicular load. As such, for concrete road no extra effort is paid on getting out of deflected ruts which is commonly encountered for bituminous pavement. Hence, vehicles using concrete road use less energy and there is about 15-20% less fuel consumed when using concrete road when compared with bituminous road.

*C*orrugated crash barriers

The layout of corrugated beam barriers is that the beams are corrugated in the longitudinal direction so that it provides higher lateral stiffness with a thinner material. Moreover, the distance of beams posts and crashing vehicles are considerably increased.

In case the beam barriers are tensioned, it is intended to create a stiff beam erected on relatively weak posts. During vehicle collision, the posts would be separated from the beams and there would be lesser

deceleration experienced by the vehicles [48].

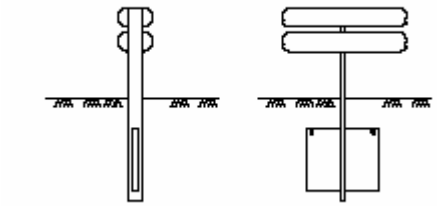

Fig. 7.2 Beam barrier.

*C*oncrete crash barriers – its application

Concrete crash barriers are not considered as the best barrier design because of the following reasons when compared with flexible barriers:

(i) Concrete barriers possess rough surface which, when impacted by moving vehicles, tend to cause considerable damage to the vehicles.
(ii) Since concrete is a rigid material and the deceleration of collided vehicles is comparatively large when compared with flexible barriers.

However, concrete crash barriers have particular application in locations where the deflection of barriers is not allowed. For instance, in the central divider of a carriageway, if flexible barriers are adopted and vehicles crush into the barriers, the deformation resulting from the hitting of vehicles would result in an intrusion to the adjacent carriageway. This is undesirable because this may trigger further collisions in the adjacent carriageway and hence rigid barriers like concrete crash barriers should be adopted in this scenario.

*D*irection of placing the main weight of reinforcement in concrete pavement

The reinforcement of concrete pavement is usually in the form of long

mesh type. A road usually has length is generally much longer than its width and therefore cracking in the transverse direction has to be catered for in design. Reinforcement is required in the longitudinal direction to limit transverse cracking while transverse steel acts to provide rigidity to support the mesh fabrics. For long mesh in concrete slab, the main weight of reinforcement should be placed in the critical direction (i.e. longitudinal direction) to control cracking. However, if the concrete road is quite wide, certain reinforcement has to be placed in the transverse direction in this case to control longitudinal cracking [55].

*F*unction of waterproof (or separation) membrane for concrete carriageway

A layer of waterproof (or separation) membrane is normally placed between sub-base and concrete slab for the following reasons [21]:

(i) It prevents the loss of water from cement paste which affects the strength of concrete slab.
(ii) It enhances the movement of concrete slab relative to sub-base layer and reduces the frictional forces developed at their interface.
(iii) It avoids the possibility of active aggressive agents from soil water being attached to the concrete slab.
(iv) It prevents the intermixing of freshly placed concrete with loose materials on the surface of sub-base.

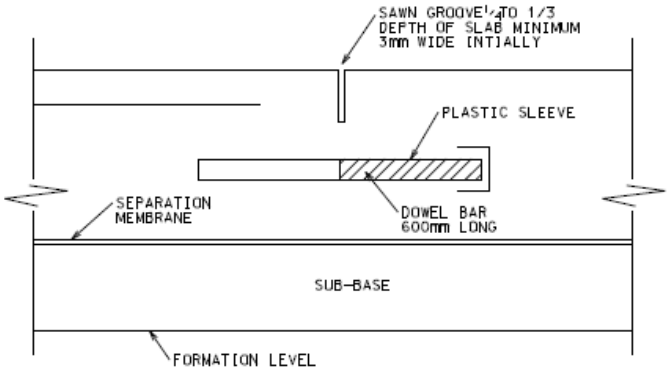

Fig. 7.3 Location of separation membrane in concrete carriageway.

*F*unction of prime coat in bituminous pavement

The principal function of prime coat in bituminous pavement is to protect the subgrade from moisture and weathering. Since the presence of moisture affects the strength of subgrade, the prevention of water entry during construction is essential to avoid the failure of the pavement. In cold countries, by getting rid of moisture from subgrade, the danger of frost heave can be minimized.

Prime coat is an asphalt which, when applied evenly to the surface of sub-base or subgrade, serves to seal the surface to hinder the penetration of moisture into subgrade. Vehicular traffic should be avoided on the surface sprayed with prime coat because the traction and tearing action of vehicles would damage this asphalt layer.

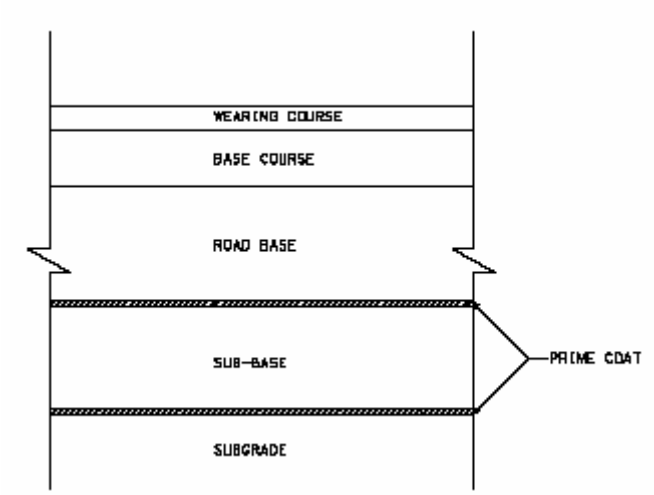

Fig. 7.4 Position of application of prime coat

*G*ood surface regularity for sub-base in concrete pavement

The surfaces of sub-base material for concrete carriageway should be constructed in a regular manner because of the following reasons [21]:

(i) One of the main functions of sub-base in concrete pavement is to provide a smooth and even interface between concrete slab and

subgrade so that a uniform support is established. A regular surface of sub-base assists in reducing the frictional and interlocking forces between concrete slab and sub-base and allowing easier temperature and shrinkage movement.

(ii) A uniform sub-base surface is essential in the construction of concrete slab of uniform thickness adopted in design. It saves the higher cost of concrete to make up the required level.

*H*igh-yield steel vs mild steel as road reinforcement

High yield steel is the preferred material for the reinforcement of concrete carriageway because of the following reasons [55]:

(i) The principal function of steel reinforcement in concrete pavement is to control cracking. If mild steel is adopted for reinforcement, upon initiation of crack formation mild steel becomes overstressed and is prone to yielding. High yield steel offers resistance to crack growth. The above situation is commonly encountered where there is abnormal traffic loads on concrete carriageway exceeding the design limit.

(ii) High-yield steel is less prone to deformation and bending during routine handling operation.

(iii) In the current market, steel mesh reinforcement is normally of high-yield steel type and the use of mild steel as road reinforcement requires the placing of special orders to the suppliers.

*H*igh temperature in laying bituminous pavement

In general, bituminous materials are also broadly classified into two types, namely bitumen macadams and hot-rolled asphalts. During compaction, the increase of temperature causes the reduction of viscosity of binder. The binder acts as a lubricant among aggregates particles because it is mobile in a fluid state under high temperatures. The internal resistance between the bituminous materials is drastically reduced resulting in the formation of a mixture with better aggregate interlock.

Bitumen macadams mainly contain continuously graded aggregates. Compaction of this type of bituminous material is eased with an increase of mix temperature as the lubricating effect of reduced viscosity of binder helps in the rearrangement of aggregates.

The aggregate of hot-rolled asphalt are not well graded. With a rise in mixing temperature, the binder will stay unset and the mixture has little resistance to compaction [38].

*K*erb overflow weirs – horizontal bars vs vertical bars

Overflow weirs should be provided for steep roads (longitudinal gradient>5%) , flat roads (longitudinal gradient<0.5%), sag points and blockage blackspots. For steep roads, flow is rapid and overflow weirs should be provided to accommodate the excess flow. For flat roads, the probability of accumulation of rubbish increases. Therefore, overflow weirs should be provided in these locations to bypass the stormwater flow in case of blockage of gullies caused by trapping of rubbish.

Basically, kerb overflow weirs suffer from the drawback that it provides another passage for debris to enter the gullies and therefore bars (either horizontal or vertical) should be provided to prevent the entry of debris into the weirs. For steep roads, as the main concern is to provide an alternative route for excess flow, horizontal bars should be provided in this case to maintain better drainage efficiency. For flat roads, the purpose of overflow weirs is to trap rubbish and therefore, vertical bars should be provided because it is more effective in prevention of entry of debris [33].

*L*ocal vehicle parapet strong enough to contain vehicles?

The majority of local parapets are 1.1m high and they are designed to resist impact from a 1.5ton car moving at a speed of 113km/hr. In some locations such as in the vicinity of railway lines, barriers with 1.5m high are provided to contain a vehicle with 24ton at a speed of 50km/hr.

The impact situation for vehicles varies from event to event and they are dependent on the speed, size and angle of incidence of the impacting vehicle. Though full-scale crash test is the simplest way to prove their performance, computer simulation has been used extensively owing to its lower in cost. Based on the results of computer simulation and crash tests, it is established that the said parapets comply with international standard for safe usage.

*M*echanism of compaction by paver, steel-wheeled roller and pneumatic tire rollers

Paver, steel-wheeled roller and pneumatic tire roller compact bituminous material by using the following principles:

(i) The static weight of the paving machines exerts loads on the bituminous material and compresses the material directly beneath the machine. The compacting effort increases with the period of contact and larger machine weight.
(ii) Compaction is brought about by the generation of shear stress between the compressed bituminous material under the machine and the adjacent uncompressed bitumen.

*M*echanism of taking up loads for concrete paving blocks

The paving for concrete blocks consists of closely packed paving blocks in pre-determined patterns and the tiny joint spaces between individual blocks are filled with sand. The presence of sand avoids the displacement of a single block unit from the remaining blocks. Moreover, the horizontal interlocking provided by the arrangement of paving blocks in special patterns (e.g. herringbone pattern) prevents any single block from moving relative to one another. For instance, vertical loads acting directly on one concrete paving block are not only resisted by the block itself, but also by the blocks adjacent to it [59].

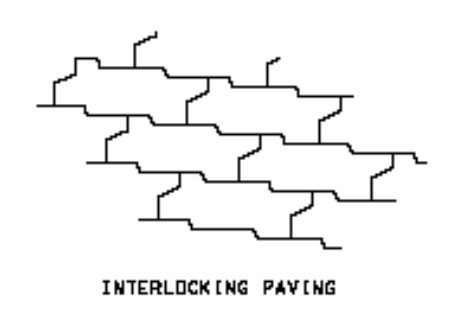

Fig. 7.5 Paving blocks.

"*M*ortar mechanism" vs "stone contact mechanism" in bituminous materials

"Stone contact mechanism" applies to well graded aggregates coated with bitumen (e.g. dense bitumen macadam) where the traffic loads on bituminous roads are resisted by stone-to-stone contact and by interlocking and frictional forces between the aggregates. It is essential to adopt aggregates with a high crushing strength. The bitumen coatings on the surface of aggregates merely serve to cement the aggregates together.

"Mortar mechanism" involves the distribution of loads within the mortar for gap-graded aggregates (e.g. hot rolled asphalt). The mortar has to possess high stiffness to prevent excessive deformation under severe traffic loads. It is common practice to introduce some filler to stiffen the bitumen.

*N*oise absorptive materials – how it works

The basic mechanism of noise absorptive material is to change the acoustic energy into heat energy. The amount of heat generated is normally very small due to the limited energy in sound waves (e.g. less than 0.01watts). The two common ways for energy transformation are:

(i) Viscous flow loss
The absorptive material contains interconnected voids and pores into which the sound energy will propagate. As sound waves pass through

the material, the wave energy causes relative motion between the air particles and the absorbing material and consequently energy losses are incurred.

(ii) Internal fiction
The absorptive materials have some elastic fibrous or porous structures which would be extended and compressed during sound wave propagation. Other than energy loss due to viscous flow loss, dissipation of energy also results from the internal friction during its flex and squeezing movement.

*N*ecessity of air voids in bituminous pavement

If the presence of air voids is too high, it leads to an increase of permeability of bituminous pavement. This allows the frequent circulation of air and water within the pavement structure and results in premature hardening and weathering of asphalt. Therefore, too high an air void content poses detrimental effect to the durability of the bituminous pavement.

If the presence of air voids is too low, flushing, bleeding and loss of stability may result under the effect of prolonged traffic loads because of the rearrangement of particles by compaction. Aggregates may become degraded by traffic loads leading to instability and flushing for such a low air void content. The air void space can be increased by adding more course or fine aggregates to the asphalt mix. Alternatively, if asphalt content is above normal level, it can be reduced to increase air voids [61].

*O*il interceptors

Grease and oils are commonly found in stormwater runoff from catchments. They come from the leakage and spillage of lubricants, fuels, vehicle coolants etc. Since oils and grease are hydrocarbons which are lighter than water, they form films and emulsions on water and generate odorous smell. In particular, these hydrocarbons tend to stick to the particulates in water and settle with them. Hence, they

should be trapped prior to discharging into stormwater system. Oil interceptors are installed to trap these oil loads coming from stormwater. In commercial areas, car parks and areas where construction works are likely. It is recommended to establish oil-trapping systems in these locations.

Typical oil interceptors usually contain three compartments:

(i) The first inlet compartment serves mainly for the settlement of grits and for the trapping of floatable debris and rubbish.
(ii) The second middle compartment is used for separating oils from runoff.

*O*ptimum binder content in bituminous pavement

The amount of binder to be added to a bituminous mixture cannot be too excessive or too little. The principle of designing the optimum amount of binder content is to include sufficient amount of binder so that the aggregates are fully coated with bitumen and the voids within the bituminous material are sealed up. As such, the durability of the bituminous pavement can be enhanced by the impermeability achieved. Moreover, a minimum amount of binder is essential to prevent the aggregates from being pulled out by the abrasive actions of moving vehicles on the carriageway.

However, the binder content cannot be too high because it would result in the instability of the bituminous pavement. In essence, the resistance to deformation of bituminous pavement under traffic load is reduced by the inclusion of excessive binder content.

*P*urpose of reinforcement in concrete roads

The main purposes of reinforcement in concrete roads are [21]:

(i) to control the development and pattern of cracks in concrete pavement.
(ii) to reduce the spacing of joints. In general, joints and reinforcement

in concrete structures are common design measures to cater for thermal and shrinkage movement. Hence, the inclusion of reinforcement allows the formation of tiny cracks in concrete pavement and this allows wider spacing of joints.

In fact, the amount of reinforcement in concrete slab is not substantial and its contribution to the structural strength of roads is not significant.

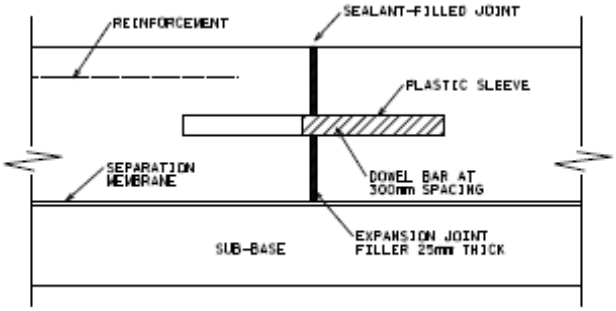

Fig. 7.6 Road reinforcement.

"*P*umping" at joints in concrete carriageway

Pumping at joints in concrete carriageway occurs in the presence of the following factors:

(i) Fine-grained subgrade;
(ii) Seepage of water into subgrade due to improper or inadequate drainage design;
(iii)The presence of heavy vehicular loads.

It involves the pumping out of water-borne particles of the subgrade owing to the deflections at the end of concrete slab. The first mechanism of pumping involves the softening of subgrade by water and the reduction in bearing capacity. It causes a larger instantaneous deflection at the slab ends under heavy traffic loads. During deflection, water containing fine soil particles is pumped out at the joints. Consequently, voids are formed in subgrade region and the void size grows by repeating the above sequence [21].

*P*urpose of using capping layers in pavement construction

When the California Bearing Ratio of subgrade is checked to be below a certain percentage (e.g. 5%), a capping layer is normally provided to reduce the effect of weak subgrade on the structural performance of the road. It also provides a working platform for sub-base to be constructed on top in wet weather condition because the compaction of wet subgrade is difficult on site. The effect of interruption by wet weather can be reduced significantly and the progress of construction works would not be hindered. Most importantly, the cost of capping layers is low because the material can be readily obtained locally.

*P*urpose of tar in bituminous materials

Tar is commonly incorporated in bituminous materials because of the following reasons:

(i) Blending of tar with bitumen possesses better binding performance with roadstone than bitumen.
(ii) Resistance to fuel oil erosion is high. Tar is used in roads where there is frequent spillage of fuel from vehicles.

*R*oadbase vs basecourse in flexible carriageway

Roadbase is the most important structural layer in bituminous pavement. It is designed to take up the function of distributing the traffic loads so as not to exceed the bearing capacity of subgrade. In addition, it helps to provide sufficient resistance to fatigue under cyclic loads and to offer a higher stiffness for the pavement structure.

However, the basecourse is normally provided to give a well-prepared and even surface for the laying on wearing course. Regarding the load distribution function, it also helps to spread traffic loads to roadbase but this is not the major function of basecourse.

Sand layer vs cement sand used as bedding of precast concrete paving units

Cement sand is a mixture of cement and sand and it acts as a cohesive mass once mixed. Normally, a 20mm to 30mm sand layer is laid underneath precast paving block units. However, in locations of steep gradients where it stands a high possibility that rain runoff will wash out infilling sand and sand layers, cement sand should be sued instead. Similarly, when high pressure jetting is anticipated to be employed frequently in routine maintenance, sand layers beneath precast paving block units is not preferable owing to the reason of potential washing out of sand.

Sub-base for concrete carriageway – non-strength provider

Basically, sub-base for a concrete carriageway is provided for the following reasons [55]:

(i) It provides a smooth and even surface between the subgrade and concrete slab. This avoids the problem of uneven frictional stresses arising from the uneven interface under thermal and shrinkage movement. It also improves the uniformity of support provided to concrete slab to enhance even distribution of wheel load to the subgrade.
(ii) For heavily trafficked carriageways with frequent occurrence of a high water table, it serves to prevent the occurrence of mud pumping on clayey and silty subgrade. The loss of these clayey soils through carriageway joints such as contraction and expansion joints will cause structural failure of concrete slab under heavy traffic load.

The stiffness of concrete slab accounts for the strength of rigid road structure. It is normally uneconomical to employ sub-base as part of the strength provider because a much thicker layer of sub-base has to be adopted to reduce the thickness of concrete slab by a small amount. Hence, it is more cost-effective to increase the depth of concrete slab rather than to enhance foundation strength in order to achieve a higher load-carrying capacity of the concrete pavement.

*S*kid resistance of wearing course

The skid resistance of wearing course in a bituminous pavement is contributed by the macrotexture (i.e. the general surface roughness) and the microtexture (i.e. the protruding from chippings) of the wearing course [38]. These two factors affect the skid resistance of flexible carriage in different situations. For instance, when the carriageway is designed as a high-speed road, the tiny channels among the macrotexture help to drain rainwater to the side of the road and avoid the occurrence of aquaplaning. In low speed roads the microtexture has particular significance in providing skid resistance by gripping the car tyres to the road surface.

*T*ack coat – emulsified asphalts vs cutback asphalts

Emulsified asphalt is a suspension of asphalt in water by using an emulsifying agent which imposes an electric charge on asphalt particles so that they will join and cement together. Cutback asphalt is simply asphalt dissolved in petroleum. The purpose of adding emulsifying agent in water or petroleum is to reduce viscosity of asphalt in low temperatures.

The colour of emulsion for tack coat is brown initially during the time of application. Later, the colour is changed to black when the asphalt starts to stick to the surrounding and it is described as “break”. For emulsified asphalts, when water has all evaporated, the emulsion is said to have “set”. Cutback emulsion is described to have been “cured” when the solvent has evaporated. There are several problems associated with cutback asphalts:

(i) Emulsified asphalt can be diluted with water so that a low application rate could be achieved.
(ii) The evaporation of petroleum into atmosphere for cutback asphalt poses environmental problem.
(iii) The cost of production of petroleum is higher than that of emulsifying agent and water.

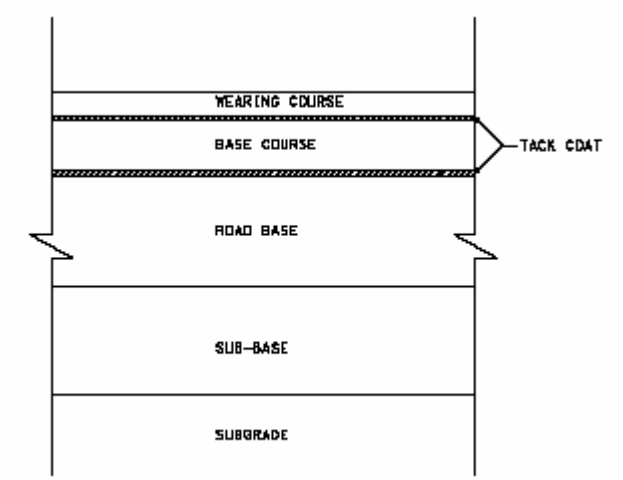

Fig. 7.7 Position of application of tack coat.

*U*nsealed contraction joints in concrete pavement

For unreinforced concrete pavement, the contraction joint is an approximately 3mm wide groove with a depth of about one-third to one-fourth of slab thickness and a regular spacing of normally 5m. The grooves are designed such that they are too narrow for stones to fall into when the cracks are open due to the contraction of concrete. The groove location is ł a plane of weakness and the groove acts as a potential crack-inducing device where any potential cracks due to shrinkage and thermal contraction may form will be confined to the base of the groove. It will not cause any unpleasant visual appearance on the exposed surface of unreinforced concrete pavement.

The above-mentioned contraction joints can be designed as unsealed. These grooves are very narrow so that stones can hardly get into these grooves even when the joint undergoes contraction. The fine particles or grit entering into the groove are likely to be sucked out by the passing vehicles. The joints can be self-cleansing and it may not be necessary to seal the joints for fear of attracting the accumulation of rubbish and dirt [55].

Chapter 8. Steelworks

Acetylene gas cylinder for gas welding to be erected in upright position

Acetylene gas is commonly used for gas welding because of its simplicity in production and transportation and its ability to achieve high temperature in combustion (e.g. around 5,000^{o}F). Acetylene is highly unstable and flammable and would explode in elevated pressure when reacting with oxygen in air. Storing acetylene gas in cylinders under pressure is very dangerous. Gas acetylene used for welding purposes is stored in cylinders of liquid acetone contained in porous material (like firebrick). This is for cooling purpose in the event of thermal decomposition and to ensure that there is no free space left for acetylene gas. It also prevents the formation of high-pressure air pockets inside the cylinder. Dissolved acetylene in acetone will no longer be in contact with oxygen and is not subject to decomposition. Acetone is used because it is capable of dissolving large amount of acetylene gas under pressure without changing the nature of the gas.

The cylinders for gas welding i.e. oxygen cylinders and acetylene cylinders, when not in use should be stored separately because any mixture of these gases resulting from accidental leakage can be highly explosive. When in use, acetylene cylinders should always be kept in upright position. Otherwise, acetone liquid will be drawn from the cylinders with the gas if they are kept horizontally, resulting in significant leakage of acetone liquid will result.

Note: Oxygen and acetylene gas cylinders are commonly used in construction sites for gas welding.

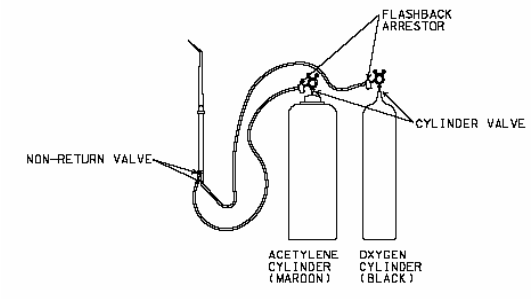

Fig. 8.1 Acetylene gas cylinder erected in upright position.

*B*utt weld – from one side vs from both sides

In the design of butt weld strength, it is generally assumed that its strength is at least equivalent to the parent metal. To enhance proper welding operation, the gap between two metals to be welded should not be too small, otherwise the root would be inadequately fused during welding and the butt weld strength would be reduced. On the other hand, the gap should be not set too large because the weld metal would simply pass through it. The function of the gap between adjoining root faces is to increase the depth of penetration down to the root of the weld.

However, it is not always possible to have access to both sides of the butt weld. Hence, the use of backing plates or rings can enhance the quality of welding from one side only. By inserting a backing plate inside the steel member, the correct alignment could be maintained and certain amount of tolerance on longitudinal fit can be permitted [47].

*C*astellated beams – Reasons for its widespread usage

Castellated beams refer to the type of beams which involve expanding a standard rolled steel section in such a way that a predetermined pattern is cut on section webs and the rolled section is cut into two halves. The two halves are joined together by welding and the high points of the web pattern are connected together to form a castellated beam. The castellated beams were commonly used in Europe in 1950s due to the limited ranges of the available steel rolled section and the cheap labour cost. In terms of structural performance, the operation of splitting and expanding the rolled steel sections helps to increase the section modulus of the beams. Moreover, it is versatile for its high strength to weight ratio so that lighter section can be designed with subsequent cost saving in foundation [20].

*C*orrosion inhibitors

Corrosion inhibitors are chemical substances that, when added in small concentrations, stop or reduce the corrosion or reaction of the metal

with the environment. It normally functions by one or more of the following mechanisms [50]:

(i) It may alter the external environmental conditions by taking away or inactivating an aggressive agent;
(ii) It may adhere to form a film on the surface of the metal;
(iii) It brings about the formation of corrosion products.

*F*ire resistance of steelwork

Owing to the high thermal conductivity of steel, the temperature of unprotected steel is almost the same as the temperature of fire. Since the yield strength of structural steel drops approximately by half when its temperature rises to about 550^{o}C, it is usually provided with some forms of insulation. The consequence of the outbreak of fire in proximity of unprotected structural steel is the potential loss of load carrying capacity of steel and the occurrence of substantial movement of steel.

*H*igh strength friction grip (HSFG) bolts vs normal bolts

HSFG bolts have the following advantages when compared with normal bolts [47]:

(i) The performance of preloaded HSFG bolts under fatigue loading is good because the prestressed bolts are subjected to reduced stress range during each loading cycle when compared with unloaded bolts.
(ii) For structures adjacent to machinery which generate substantial vibration, preloading bolts can help to avoid the loosening of bolts.
(iii) HSFG bolts are used in connections where any slight slip movement would render the integrity of the whole structures break down.
(iv) Owing to its high tensile strength, it is commonly used in connections which require the taking up of high flexure and the tensile stress generated could be readily resisted by it high tensile strength.

*I*nsulating washer between steel bolts and connecting aluminium plates

Corrosion of aluminium can be triggered by putting it in contact with another metal in the presence of water. This is known as bimetallic corrosion or galvanic corrosion. The mechanism of such corrosion is the formation of a cell in moist condition so that an electric current is generated to flow between the two metals in direct contact. The degree of corrosion is influenced by the nature of connecting metals, their electrode potential, their areas, conductivity of fluid etc.

When aluminium plates are connected together by means of steel bolts, bimetallic corrosion may occur. Where there is presence of a good electrolyte like seawater, there may be local attack on aluminium. Therefore, some jointing compound or insulating insert and washer are adopted to insulate electrically the dissimilar metals from one another [1].

*I*nterface between base plates and footings

The surface of footings is normally quite rough so that some leveling has to be carried out for the base plates. The interface between the base plates and footings after leveling is subsequently filled with grout. During grouting, trapping of air may occur at the underside of base plates and this leads to the formation of cavities and uneven contact surfaces on which the base plates are rested. As such, some holes may be drilled in the base plate to avoid the occurrence of air trapping [63].

*I*nternal force of preloaded fasteners

The force in a bolt in a bolted joint depends on the preloading force applied to it during the tightening operation. For instance, when the preloaded bolt is tightened with a certain force, the bolts' internal force will not increase significantly if the external applied force on the bolted joint does not exceed the preloading force. It looks like the bolt does not feel the external applied force and it is not until the external force has exceeded the preloading force when a substantial increase of

internal force of the bolt will occur.

*P*aint system to protect steelwork from corrosion

In a typical painting system, there are normally three main layers, primer, undercoat and finishing coat. The primer acts as the first coat of the painting system and adheres to the substrate. It serves to provide a foundation for other coats. The mid-coat, undercoat, is designed to increase the film thickness and hinder the background colour. Moreover, it aids in the reduction of permeability by incorporating pigments like micaceous iron oxide. Finally, the finishing coat contributes to the appearance of the painting system like colour. Sometimes, it may be designed to provide additional abrasive resistance. However, in terms of corrosion protection to steelworks, it does not add much value.

The main component which serves to inhibit corrosion is the primer because it is in direct contact with steel surface. In general the primer is pigmented with inhibitors like zinc and zinc phosphate which protect the steelwork by sacrificial protection [27]. Initially the primer is porous and the products generated by sacrificial protection of zinc fills these voids and the primer acts as a barrier.

*P*urpose of pedestals

When structural steelworks are connected to the foundation, pedestals are normally designed to carry loads from metal columns through the ground surface to the footings which are located below the ground surface. With the installation of pedestals, it is the pedestals, instead of metals, which come into contact with soils. The purpose of the provision of pedestals is to avoid the direct contact of metal columns with soils which may cause possible metal corrosion by soils. The soils around the pedestals should be properly compacted to provide sufficient lateral resistance to prevent buckling of pedestals [9].

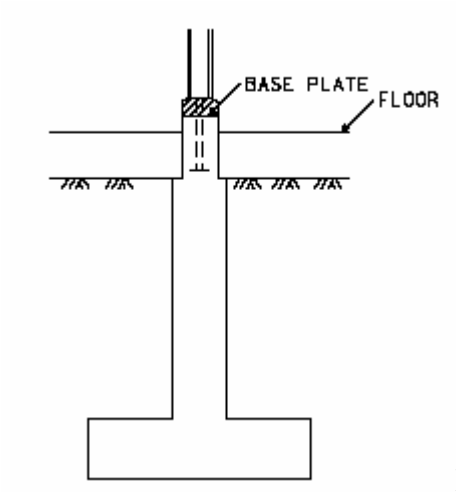

Fig. 8.2 Pedestal.

*R*esidual stresses in steel after welding

Considerable residual stresses are induced in connecting steel members after the welding operation. The local temperature of steel where welding takes place is higher than the remaining parts of the connecting steel members. This causes thermal expansion locally during welding and the subsequent contraction after welding. Tensile stresses associated with the thermal contraction generated during the cooling process are balanced by compressive stresses in the remaining parts of connecting steel members. As a result, residual stresses are induced during the welding operation.

*W*asher – necessary for bolts?

"Fastener" is a general term used to describe something which is used as a restraint for holding things together or attaching them to other things.

The main physical distinction between screws and bolts is that screws are entirely full of threads while bolts contain shanks without threads. However, a better interpretation of the differences between the two is that bolts are always fitted with nuts. On the contrary, screws are normally used with tapped holes.

High friction grip bolts are commonly used in structural steelwork. They normally consist of high tensile strength bolts and nuts with washers. The bolts are tightened to a shank tension so that the transverse load across the joint is resisted by the friction between the plates rather than the bolt shank's shear strength.

The purpose of installing washers in a typical bolting system is to distribute the loads under bolt heads and nuts by providing a larger area under stress. Otherwise, the bearing stress of bolts may exceed the bearing strength of the connecting materials and this leads to the loss of preload of bolts and the creeping of materials. Alternatively, flanged fasteners instead of using washers could be adopted to achieve the same purpose.

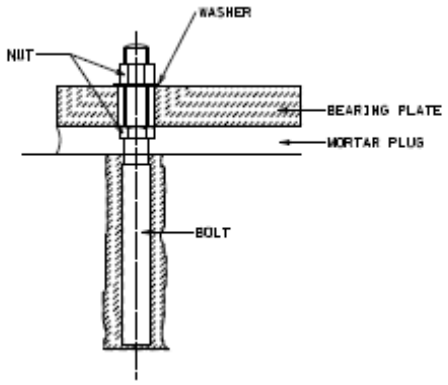

Fig. 8.3 Washer.

Chapter 9. Waterworks and tunneling

Air chamber vs surge tank in pressurized pipelines

Air chambers and surge tanks are normally installed in watermain to ease the stress on the system when valves or pumps suddenly start up and shut down. A surge tank is a chamber containing fluid which is in direct contact with the atmosphere. For positive surge, the tank can store excess water, thus preventing the water pipes from expansion and the water from compression. In case of downsurge, the surge tank can supply fluid to prevent the formation of vapour column separation. However, if the relief of surge pressure is significant, the height of surge tank has to be large and sometimes it is not cost-effective to build such a large tank. On the contrary, an air chamber can be adopted in this case because air chamber is an enclosed chamber with pressurized gases inside. The pressure head of the gas inside the air chamber can combat the hydraulic transient. The volume of liquid inside the air chamber should be adequate to avoid the pressure in the pipelines falling to vapour pressure. The air volume should be sufficient to produce cushioning effect to positive surge pressures. In essence, air chambers can usually be designed to be more compact than surge tanks. Air chamber has the demerits that regular maintenance has to be carried out to check the volume of air and proper design of pressure level of gas has to be conducted.

Axial flow pumps for large flows and low heads

It is well known that axial flow pumps are most suitable for providing large flows and low heads. The reason behind this is closely related to the configuration and design of the pumps. In axial flow pumps, the size of inlet diameter is greater than that of impeller diameter. For low flow condition the velocity is relatively small and this increases the chances of occurrence of separation which brings about additional head losses and vibration. On the contrary, if the discharge is large enough the problem of separation is minimized.

*B*est efficiency point≠operating point for pumps

In a pumping system, a system curve can be derived based on the static head required to lift up the fluid and variable head due to possible head losses. The pump curves which relate the performance of the pumping to head against discharge can be obtained from pump suppliers. When the system curve is superimposed on the pump curve, the intersection point is defined as the operating point (or duty point). The operating point may not be necessarily the same as the best efficiency point. The best efficiency point is a function of the pump itself and it is the point of lowest internal friction inside the pump during pumping. These losses are induced by adverse pressure, shock losses and friction.

Losses due to adverse pressure gradient occur in pumps as the pressure of flow increases from the inlet to the outlet of pumps and the flow travels from a region of low pressure to high pressure. As such, it causes the formation of shear layers and flow separation. Flow oscillation may also occur which accounts for the noise and vibration of pumps. The effect of adverse pressure gradient is more significant in low flow condition.

For shock losses, they are induced when the inflow into pumps is not radial and contains swirl. In an ideal situation, the flow within the pump should be parallel to the impellers such that the flow angle is very close to the impeller angle. The deviation of the above situation from design causes energy losses and vibration.

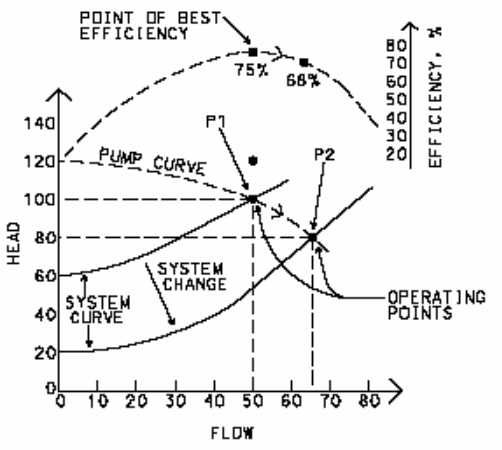

Fig. 9.1 A diagram showing point of best efficiency ≠ operating point

*B*ackward curved vanes vs forward curved vanes in pumps

The power of a pump is related to discharge as follows:

$$Power = k_1 Q + \frac{k_2 Q^2}{\tan A}$$

where k_1 and k_2 are constants, Q is discharge and A is the angle between the tangent of impeller at vane location and the tangent to vane.

For A less than 90^o (forward curved vanes) it is unstable owing to unrestricted power growth. Large losses result from high outflow velocity. The preferred configuration is achieved when A is more than 90^o (i.e. backward curved vanes) because it has controlled power consumption and presents good fluid dynamic shape.

*C*omplete embedment of pipelines into thrust blocks

For unreinforced concrete thrust blocks in bends and tees for pressurized pipelines, it is recommended that the contact surface between the pipelines and concrete thrust blocks should not exceed 45^o from either side of the pipe in the direction of thrust force through the center of pipelines [65]. The reason is to prevent the occurrence of potential cracking arising from the deformation of pipelines under loading condition. If it is necessary to embed the whole section of pipelines into concrete, it is suggested to coat the pipe with a flexible material.

*D*uctile iron pipes vs mild steel pipes as pressurized pipelines

For watermain pipe size less than 600mm, ductile iron is normally used because internal welding for steel pipes below 600mm is difficult to be carried out. Moreover, it requires only simple jointing details which allows for a faster rate of construction. For watermain pipe size above 600mm, steel pipes are recommended because steel pipes are

lighter than ductile iron pipes for the same material strength and therefore the cost of steel pipes is normally less than that of ductile iron pipes. In addition, in areas of difficult access the use of lighter mild steel pipes has an advantage over ductile iron pipes for easy handling.

*D*ifferences between open shield and closed shield for TBM

Open shield type TBM refers to those providing lateral support only. They can be further classified into single shield and double shield.

Closed shield type TBM refers to those providing lateral support and frontal support. Some common TBM method under this category includes compressed air TBM, slurry shield TBM, earth pressure balance machine and mixed confinement shield.

Compressed air TBM is suitable for cohesive soils under water table (e.g. ground with low permeability with no major discontinuities). Slurry shield TBM is suitable for soft ground and soft rock under water table and also for ground for high permeability. Earth pressure balance machine is suitable for soft ground and soft rock under water table. It is not recommended for very abrasive and hard ground.

*D*ifferences between pipe jacking and micro-tunneling

Pipe jacking is a general technique of the installation of pipes with a tunneling shield in front and the pipes are jacked from a jacking pit to a receiving pit. The tunneling shield for pipe jacking can be electrical and mechanical equipment for conducting the excavation work or it can be a manual shield for workers going inside the shield to carry out manual excavation. For microtunneling, it is a kind of pipe jacking of small sized non-man-entry pipes which are remotely controlled. In general, there are two common types of micro-tunneling machines:

(ii) Pressurised slurry
Similar to the Pressurised slurry TBM, excavated material is transported from the excavation face to the surface suspended in a

slurry.

(iii)Auger machine

Excavated material is transported from the excavation face to the drive pit through a cased screw auger.

*D*ifferences between segmentally lined tunnels and Sprayed Concrete Linings (SCL) tunnels

The basic difference between segmentally lined tunnels and SCL tunnels is that the sprayed concrete in SCL tunnel is used for temporary linings only. Concrete linings in segmentally lined tunnels are designed with long-term load conditions with the adoption of appropriate safety factors. However, the dimension of linings in SCL tunnels is derived from a balance between safety of lining and cost consideration.

The quality of precast concrete linings can be better controlled in precasting yards. As such, the quality control of precast concrete lining is obviously better than that of sprayed concrete which depends on site workmanship [39].

*G*round settlement occurs when pipe-jacking machine enters mixed ground with soils and boulders?

The rate of cutting through soils is faster than that of cutting through boulders for pipe-jacking machine. As such, when pipe-jacking machine enters a region of mixed ground with soils and boulders, the machine has the tendency to move towards the direction of soft soils because of the difference of rate of advancement of pipe-jacking machine for soils and boulders. Consequently, migration of soft soils occur which contributes to ground settlement. The degree of settlement is dependent of the depth of soil cover, soil property and the size of boulders.

Ground settlement occurs ahead or behind the jacking face for pipe-jacking?

It is reported by Lake (1992) that settlements are expected at the ground surface at a distance of 1-2 times of tunnel depth ahead of the tunnel face and 80% to 90% of settlement to be completed at a similar distance behind the face. However, in the paper "Monitoring of ground response associated with pipe jacking works – recent experience in Hong Kong", the author pointed out that based on their experience, development of longitudinal settlement was observed at a distance of 3-4 times of tunnel depth behind the tunnel face and little settlements were reported immediately above the tunneling face.

Grouting in segmental linings in tunnels

Grouting is usually carried out under pressure in segmental linings during tunnel construction because of the following reasons [62]:

(i) It helps in the uniform transfer of ground pressure to the linings.
(ii) The grout serves to reduce the surface settlement.
(iii) Grout fills up the annulus of tunnel linings so that it upholds the designed tunnel shapes.
(iv) The presence of grout aids in limiting groundwater seepage in the tunnels.

Minimum volume of sump volume for pumps

$Maximum\ pumping\ rate = Q_p$

$Volume\ of\ sump = V$

$Inflow\ Rate = Q_i$

$Cycle\ Time\ T_c = t_1 + t_2$

$$t_1 = \frac{V}{Q_p - Q_i}$$

$$t_2 = \frac{V}{Q_i}$$

T_c = *Minimum cycle time*

$$V = T_c / \left(\frac{1}{Q_p - Q_i} + \frac{1}{Q_i} \right)$$

For Minimum Volume,

$$\frac{\partial V}{\partial Q_i} = \frac{\partial}{\partial Q_i} \left\{ T_c / \left(\frac{1}{Q_p - Q_i} + \frac{1}{Q_i} \right) \right\}$$

Minimum volume occurs when $Q_i = 0.5Q_p$

$$\text{Hence, Minimum volume of sump} = T_c / \left(\frac{1}{Q_p - 0.5Q_p} + \frac{1}{0.5Q_p} \right)$$

$$= \frac{T_c Q_p}{4}$$

Necessity of air valves in pressurized pipelines

Air valves are broadly classified into two main types: single air valves and double air valves. Single air valve contains a small orifice air valve which allows automatic release of a small amount of accumulated air during normal operation of the pressurized pipeline. Double air valves contain a small orifice air valve and a large orifice air valve. The large orifice air valve exhausts air automatically during filling and permits admission of air during emptying of the pipeline. However, it cannot perform the function of a small orifice air valves.

The presence of air in the pressurized pipeline is undesirable due to the following reasons:

(i)The presence of air causes significant impedance to water flow and

in the worst case it may even cause complete blockage of the system.
(ii) The air induces considerable head loss to the system and causes the wastage of useful energy.
(iii) It may cause serious damage to meters and even cause inaccurate reading of the meters.
(iv) The presence of air causes water hammer damage to the pipeline.

The absence of air (i.e. during emptying operation of pipeline in routine maintenance) may also generate problems owing to the following:

(i) The suction generated draws in dirt and mud through faulty connections and cracks in pipelines.
(ii) The seals, gaskets and internal accessories will be suctioned inside the pipelines.
(iii) Sometimes, the suction forces may be so significant to cause collapse of pipelines.

One may query that if a large orifice air valves can perform the functions of filling and release of air, why is it necessary to add small orifice air valves in the pipeline system for release of accumulated air during normal operation? The reason is that the air accumulated at the high points of pressurized system will be expelled through the large orifice air valves (in case no small orifice air valves are installed in the system) upon starting of a pump and with such rapid outflow of air through the large valves, high slam pressure may be produced resulting in the damage of the pipelines.

*N*umber of segments for segmental linings in tunneling

For the construction of tunnels by segmental linings, the choice of the number of segments affects the cost and durability of tunnels. With an increase in the number of segments, the number of joints also increases accordingly. This raises the potential for water ingress into the tunnels.

However, if the number of segments is kept to a minimum, the speed of the erection of segments can be increased. However, it is expected that higher bending moment would be induced in the tunnel rings for

smaller number of segments and extra cost is incurred in the provision of additional reinforcement.

*P*otential advantages of segmental tunneling when compared with hand-shield pipe-jacking

In segmental tunneling, the jacks are installed at the shield so that it is not necessary to install thrust wall at the jacking pit. This provides the opportunity for smaller size of the pit because of the absence of thrust wall. Moreover, as the jacking operation involves the jacking of small length of segmental liner plates and hence smaller force would be required for pipe jacking when compared with traditional pipe jacking (jacks at jacking pits) where the jacking force is needed to overcome long lengths of pipe drives. On the other hand, the use of segmental tunneling offers better control in alignment because the steering operation could be performed at the shield.

*P*urpose of embedding puddle flange inside the walls of closed valve chambers

When valves are closed to stop water flow in a pipeline, a thrust is generated along the direction of the pipeline. Hence, it is necessary to restrain the valves during closure to prevent it from moving in the thrust direction. If the closed valve is situated inside valve chambers, it is connected to a puddle flange embedded inside a wall of the chamber. As such, the closed valves can be effectively restrained from the thrust action during the closure of valves.

*P*urposes of subdivision of tunneling faces in Sprayed Concrete Linings (SCL) method

In employing sprayed concrete lining methods for lining a large tunnel in soft ground, the tunneling face is normally divided into several parts because of the following reasons [62]:

(i) It enables early closure of part of the invert of the tunnel.

(ii) With the excavation in each part taking place at different times, it helps to reduce the area of exposure of the tunnel face so that there is better control on tunnel stability.

(iii) For unit advancement in any part of the tunnel excavation, the amount of excavation and sprayed concrete is reduced. As such, this allows for early provision of primary support.

*P*ressure balance method vs compressed air method in pipe jacking

Pressure balance method normally requires the use of mechanically operated tunnel-boring machine at its cutting head in pipe jacking. Slurry or steel bulkhead is commonly adopted to provide the balance of earth pressure and groundwater in front of the boring machine. Slurry used in balancing earth pressure and ground water pressure is constantly supplied to the face of the cutting wheel through slurry pipes. The excavated materials drop into a crusher for reduction in material size. Later, the debris and spoils will enter the spoil removal chamber near the invert of the shield and will be transported to ground level through slurry discharge pipes. This method of construction is normally adopted in sand and gravel. However, it suffers from the demerit that it is quite difficult to remove large rock boulders during the advancement of the machine. It is quite time-consuming for workers to go inside the relatively small airlock chamber and remove large bounders by hand tools.

The other type of pressure balance technique is called earth pressure balance method which is commonly used in clay and silty soils. It makes use of the principle of maintaining the pressure of excavation chamber the same as the pressure in ground. The excavated materials are transported through screw conveyor to the jacking pit.

Compressed air method in pipe jacking is commonly adopted in locations where groundwater table is high. An air pressure of less than 1 bar is usually maintained to provide the face support and to avoid water ingress. Pressurization and depressurization has to be conducted for workers entering and leaving the pipe-jacked tunnels. In case of porous ground, certain ground treatment like grouting has to be carried out. The removal of boulders by this method is convenient but it has

the disadvantages of slow progress and significant noise problem generated by generators and compressors.

*R*adial flow pumps for small flows and high heads

In radial flow pumps, a diffuser/volute is normally designed at it outlet to convert the kinetic energy gained during the pumping process to pressure head. The diffuser is characterized by widening of outlet pipes, resulting in the decrease of velocity (by continuity equation) and an increase in pressure head (by Bernoulli's equation). In case of large flows to be handled by the pumps, the large velocity results in formation of significant Coriolis force which tends to deviate the outlet flow from design conditions.

At the inlet part of the pumps, the inlet size is smaller than the diameter of the impeller. Consequently, the velocity of flow associated with a small area is relatively large and there is less problem of separation in low flow condition. All in all, the efficiency of radial flow pumps is high when handling small flows.

*R*easons of ground heaving during pipe-jacking

It is commonly recognized that ground settlement is one of the major concern in pipe jacking operation. However, engineer should also pay attention to the problem of ground heaving during grouting work of pipe-jacking. For instance, if excessive slurry or grout pressure is applied so as to exceed the overburden pressure, ground heaving would result. Alternatively, if the ground contains loose soils with high porosity, the same phenomenon also occurs. Proper control on the applied pressure and viscosity of grout/slurry is necessary to prevent such occurrence.

*R*einforcement in thrust blocks

In normal situation, reinforcement is not required for thrust blocks in pressurized pipelines. However, certain amount of reinforcement has

to be added in thrust blocks in the following situations [65]:

(i) The structure integrity of huge thrust block could be enhanced by the introduction of reinforcement.
(ii) At the anchorages for straps in thrust blocks, some reinforcement has to be designed to avoid the development of tensile stresses.

*S*ervice reservoirs – a necessity?

Service reservoirs, other than normal reservoirs, are provided because of the following reasons:

(i) In case of the breakdown of pumping stations and water treatment plants, it provides a temporary storage of water in emergency situation like fire fighting.
(ii) Since the demand of water supply from customers varies with time, the provision of service reservoirs aims to balance the fluctuation rate of water demand.
(iii) It provides a constant head of water to the distribution system under the design pressure.
(iv) In the event of the occurrence of water hammer or surge during the rapid closure and opening of pumping stations, the reservoir acts to attenuate the surge and performs like a surge tank.
(v) It leads to a reduction of the size of pumps and trunk mains connecting to the distribution system as the pumps are not required to directly cope with the peak rates of water demand by the introduction of service reservoirs. As such, there is substantial cost savings arising from the use of smaller pumping pipelines and smaller pumps.

*W*hy does pipejacking machine usually get stuck when the ground condition change from soil to very hard rock?

When the pipejacking machine moves from a region of soil to very hard rock, it will be subject to damage of cutting disc. To break and loosen the rock, the pipejacking machine applies a large torque on cutting wheels. However, with the change of soft region to hard region,

the pipejacking machine is still under the same jacking load. As such, this results in insufficient or little space for the movement of the machine against the rock face, leading to damage and exhaustion of the pipejacking machine.

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Backcover

About the Author

Vincent T. H. CHU (朱敦瀚) , famed as *walking encyclopedia of civil engineering* (有 Civil 百科全書的外號), obtained the degree of civil and structural engineering in the University of Hong Kong. He is the author of the monthly column "The Civil FAQ" in the Hong Kong Engineer published by the Hong Kong Institution of Engineers and is the author of the civil engineering monthly columns "The Civil Q&A" and "The Civil Corner" on the websites on World Federation of Engineering Organization and the University of Science and Technology (American Society of Civil Engineers – International Student Group) respectively. He is the recipient of the Ombudsman's Award 2007 under complaint-related category and Young Engineer of the Year Award 2008 (Merit) organized by the Hong Kong Institution of Engineers. He is also the author of the engineering book "200 Question and Answers on Practical Civil Engineering Works", which is widely publicized and posted on the websites of following engineering organizations and universities around the world:

EUROPE

Posted on Engineering Websites

- European Council of Civil Engineers ECCE
  http://www.ecceengineers.eu/papers/index.php

- Institution of Civil Engineer (United Kingdom)
  http://www.ice.org.uk/knowledge/document_details.asp?Do

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- Hemsley Orrell Partnership (Consulting Civil & Structural Engineers)
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The author has established a free Civil FAQ email service called "Ask Vincent Chu" (email: askvincentchu@yahoo.com.hk) in which he would answer civil engineering queries raised from engineers (especially young engineers).

Interested readers could refer to the personal interview of the author regarding his further background information:

(i) Face Magazine on 2 December 2008
http://education.atnext.com/index.php?fuseaction=Article.View&articleID=11925677&issueID=20081203

(ii) Jiu Jik 招職 on 30 September 2008
http://www.jiujik.com/jsarticle.php?lcid=HK.B5&artid=3000022089&arttype=LEISU&artsection=CAREER