Topic 4 Bridge Construction

1. Bridge components (Fig. 4.1, 4.2):
   - **Main crossing** – the largest span of the bridge
   - **Viaduct** – elevated road leading to the main crossing
   - **Abutment** – end support for bridge beams or girders, place where the roadway ends and the bridge over the opening begins.
   - **Transition slab** – slab with one of its end supported on the abutment and the other end on grade.
   - **Deck** – flooring that supports vehicular or pedestrian traffic.
   - **Pier** – intermediate support consisting of one or more columns supporting the deck.
   - **Embankment** – filled slope
   - **Wing wall** – retaining wall to retain the fill behind the abutment, usually forms a monolithic part of the abutment.

2. Type of Bridges:

   Bridges can be classified by many ways:

<table>
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<tr>
<th>Classified by:</th>
<th>Example of bridges</th>
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<tr>
<td>Spanning structural form (Achievable Span)</td>
<td>beam bridges (&lt;300 m), truss bridges (&lt; 300m)</td>
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<tr>
<td></td>
<td>arch bridges (500 m), suspension bridges (&gt; 1000 m)</td>
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<td></td>
<td>cable stayed bridges (400 m - 1000m) (Fig. 4.3)</td>
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<tr>
<td>Purpose</td>
<td>Foot bridges, highway bridges, rail bridges.</td>
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<tr>
<td>Materials</td>
<td>Stone bridges, timber bridges, concrete bridges, steel bridges</td>
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<tr>
<td>Deck structure</td>
<td>Solid slab bridges, truss, deck-girder bridges: I beam, inverted T beam, box beam, M beam, U beam, box girder, etc.</td>
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</tbody>
</table>
Construction Technology B (CON4313)

| Construction method ((Achievable Span) | cast in-situ balanced cantilever bridges (300 m), precast segmental launching bridges (<100 m), incremental launching bridges (total length < 1000 m over individual spans <100 m). |

3. **Beam Bridge**

A beam bridge consists of a horizontal beam that is supported at each end by piers. When a load pushes down on the beam, the beam's top edge is pushed together (compression) while the bottom edge is stretched (tension).

Single span beam bridges rarely span more than 100 m. To cross great distances, they must be daisy-chained together, creating what's known in the bridge world as a "continuous span."

3.1 **Steel Deck-girder Bridge (Fig. 4.4)**

Various types of steel girders can be used, among which standard rolled steel sections are usually employed. The girders run longitudinally and supported on piers. Depending on the design loads, the spacing of the beams and the deck thickness, there may be or may not be transverse secondary beams. On top of the beams is the road deck which can be made of steel plates, precast or insitu R.C. slabs. Since steel is high in strength and light in weight, it is very suitable to use for bridge material. However, construction cost maintenance cost of steel bridges and higher than R.C. ones in Hong Kong, they are not very commonly in Hong Kong.

3.2 **Concrete Deck-Girder Bridge**

Different types concrete deck girder bridges had been used in Hong Kong. Their designs are now obsolete but many bridges are still servicing us. They include:

1. Solid slab bridge with inverted T beam (Fig. 4.5)
2. Box beam bridge (Fig. 4.6)
3. Pseudo-Box M beam bridge (Fig. 4.7)
4. M beam bridge with top slab construction (Fig. 4.8)

Since 1980s, U-beam Bridge (Fig. 4.9, 4.10, 4.11) has become the prevailing one used in Hong Kong. The U-beams are lifted by cranes and supported longitudinally between piers. The beams are placed parallel to each other with suitable spacing. Precast concrete plates, used as permanent formwork, are placed between the spacing and over the voids of the U-beams. Deck reinforcements are fixed with lapping to the exposed stirrups of the U-beams. The deck is made integral with the beams by insitu concrete.

The decks are usually simply supported on piers. They can also be made continuous by exposed reinforcement connection or post-tensioning.

The use of precast beam in bridge construction is very common but there are obvious limitations in the length and weight of precast units which can be transported, so that only spans of less than 30m are commonly used.

3.3 Concrete Box Girder Bridges (Fig. 4.12)

A concrete box girder bridge span consists of longitudinal girders with top and bottom slabs which form hollow or box girders. Box girders of prestressed concrete in the design of which the advantages of continuity are utilised, have been built with span lengths of approximately 100 m. There are various kinds of methods for constructing box girder bridges.

3.3.1 Cast insitu on falsework and formwork (Fig. 4.13)

This is a traditional method. Falsework is erected between piers and abutments. Formwork is placed on top the falsework and the bridge is cast insitu. When the entire girder (or one span) is complete, the temporary supports can be removed.

The temporary support requires that the locations for the supports be clear and stable. Often the ground is not sufficiently stable and it is necessary to construct foundations
for the temporary supports. The assembly and removal of temporary supports requires lots of equipment and labour. Therefore, it is economical for low level bridges.

3.3.2 Incremental Launching Method (Fig. 4.15)

In this scheme, a fabrication plant is set up at one or both ends of the bridge. A set of forms is mounted behind the abutment. The forms will remain in the same location and sequentially form segments of the bridge. Thus, the forms should be hydraulically or mechanically activated to ensure rapid stripping.

The launching process:
1. A segment is cast with the forms in position.
2. After stripping and sufficient curing, the segment is jacked forward, sliding on temporary Teflon bearing seats. (Teflon is a very tough, smooth and with low friction material.)
3. A new segment is then constructed immediately adjoining the rear end of the first.
4. After post-tensioning, the whole bridge beam is moved forward again whereupon the third unit is then added.
5. This process is repeated and repeated until the full length of the bridge deck has been erected and extended to the opposite abutment.

The launching can be achieved by strands and jacks, pulling forwards by repetitive strokes. Alternatively, the launching deck is jacked forwards from behind by hydraulic jacks.

The forward end of the bridge will be in cantilever. To aid in guiding it up over the next pier and in providing support, a light truss of steel or aluminium is affixed to the forward end as a ‘launching nose’. In addition, temporary props between piers can also be employed to reduce the span of temporary cantilevering.
After the launched bridge is in place, the bearing seats may be jacked up to remove the Teflon and then permanent bearings can be installed.
3.3.3 Cast in Place Balanced Cantilever Bridge (Fig. 4.16)

In cast in situ balanced cantilever bridge construction, travelling form is employed. A travelling form is a reusable form suspended on a movable frame which called traveler. The sequence of erection is chosen to keep the partially completed superstructure balanced about the pier, in double cantilever.

The construction sequence (Fig. 4.17)

1. With the formwork in place, a new bridge segment is cast.
2. After sufficient curing, it is locked to the previous segment by post-tensioning.
3. The traveller is then pushed forward and anchored to the newly formed structure.
4. With closing of the formwork, the next cycle is started.
5. The process is repeated and repeated until the span reaches the opposite abutment or closes up with the opposite span.

Since it is not feasible to cast the two segments exactly simultaneously, a step-by-step sequence is adopted, in which one segment is cast on one side, then the next one on the other side. This puts bending moments in the pier; the unbalance load is the load of the segment plus any construction equipment. Temporary towers with vertical prestressing or counterweights can provide additional support.

This method is commonly employed for large span bridges such as bridges crossing rivers or channels.
3.3.4 Segmental Launching (Fig. 4.18, 4.19, 4.20)

In this scheme, the bridges are formed by joining precast segments. Launching girders are used to place the segments. Launching girders are large trusses that are placed longitudinally over the bridge structure. There are crane devices attached to the girders which are movable and running along the girders. Precast segments are lifted up one by one by the crane devices and joined to the bridge by post-tensioning. The launching girder crawls along the alignment incrementally to complete the whole bridge deck.

Shear keys (Fig. 4.21)

Shear keys are special shaping cast on the joint faces of precast bridge segments. They help in exact alignment of the segments during assembly, lock the segments together and transmit shear forces.

3.3.5 Span-by-Span Erection (Fig. 4.22)

Span-by-span erection is typically limited to bridges that consist of box girders with constant depth. The actual construction method can have several variants:

1. All the segments of a span are be assembled on the ground and joined by post-tensioning. The whole group is lifted up by a heavy-duty crane then placed on top of the bridge piers.

2. Erection girders are placed on top of the piers. Bridge segments are hung beneath the girders or placed on top of them. The segments are aligned and joined together by post-tensioning to form a complete span. The girders are then set forward for the construction of the next span.
3.4 Truss Bridges

A truss is an open structure comprising many small rods joined together. They can support a large amount of weight and span great distances. Most truss bridges have one set of truss on each side of the roadway. Typical Span Length of a truss bridge ranges from 40m - 500m.

3.4.1 Warren Truss (Fig. 4.23, 4.24, 4.25, 4.26)

A Warren truss can be identified by the presence of many equilateral or isosceles triangles formed by the web members which connect the top and bottom chords. For smaller spans, no vertical members are used lending the structure a simple look. For longer spans vertical members are added providing extra strength.

3.4.2 Pratt Truss (Fig. 4.27)

Pratt trusses are identified by their diagonal members which, except for the very end ones, all slant down and toward the center of the span. Except for those diagonal members near the center, all the diagonal members are subject to tension forces only while the shorter vertical members handle the compressive forces. This allows for thinner diagonal members resulting in a more economic design.

3.4.3 Howe Truss (Fig. 4.28)

The Howe truss is the opposite of the Pratt truss. The diagonal members face in the opposite direction and handle compressive forces. This makes it very uneconomic design for steel bridges and its use is rarely seen.

3.4.4 Erection methods of trussed bridges:

- Temporary support method
- Prefabrication and placing method

(The methods are similar to that of arch bridges and will be discussed later.)

4 Arch Bridges
The arch profile is aesthetically pleasing and it provides a structure which eliminates tensile stresses in spanning an open space. This is useful because several of the available building materials such as stone, cast iron and concrete are strong in compression but are weak when tension.

4.1 Concrete arches

- Open spandrel arch (Fig. 4.30, 4.32)- The roadway is supported above the arch by columns and girders. This type of bridges is best suited to deep gorges with steep rocky banks which provides efficient natural abutment to receive the heavy thrust exerted by the arch.
- Spandrel-filled arch bridge (Fig. 4.29)- The arch spandrel is closed by two retaining walls and the interior is filled with earth. The roadway is placed directly on the fill
- Tied arch (Fig. 4.31, 4.34) – The road deck serviced as a tie, it is used where horizontal reaction not available from the abutments.
- Deck-through arch – The middle span of the bridge deck is hung under the arch by hangers while both ends of the bridge deck are support by columns above the arch. (Fig. 4.33)

4.2 Steel Arches

Similar to concrete arches, steel arches can be in the forms of spandrel arch, deck-through arch and tied arch.

4.3 Erection methods of arch bridges

Constructing an arch bridge can be tricky, since the structure is completely unstable until the two spans meet in the middle.

4.3.1 Erection on Falsework (Fig. 4.35)
Falsework, or "centering," below the spans are built to support the voussoirs until they are closed. After completion, the temporary supports are removed.

4.3.2 Cantilever Method (Fig. 4.36)

Usually, the side spans of the bridge on land are erected first on temporary falsework. These side spans then serve as counter weights as the girder is assembled toward the center.
Alternatively, the unbalanced-weight can be replaced by a cable restraining each of the two halves of the arch connected to a massive anchorage on each bank.

4.3.3 Prefabrication and Placing (Fig. 4.37)

Often conditions under the bridge are not suitable for the use of temporary supports. This can happen when the valley or ravine is too deep, the flow of a river is too rapid, or environmental reasons prevent the use of temporary supports under the bridge. An arch can be erected by prefabrication and placing.

There are various methods for placing the prefabricated bridge. If conditions on both sides of the bridge are suitable to erecting towers and placing cable anchorages, the cable erection method can be used.
5. Cable Stayed Bridges

The cable stayed bridge is specially suited in the span range of 200 to 500 m. The main components of a cable stayed bridge are:

- towers or pylons
- inclined cables, and
- deck.

5.1 The Bridge deck (Fig. 4.38)

The bridge deck can be made of steel, R.C., or more often composite materials. A typical one, Kap Shui Mun Bridge for example, uses sloping steel plate side walls (called webs) for strength and light weight, joined to reinforced concrete slabs which form the upper and lower roadways. (Steel roadways would be much lighter but stiffening them to resist the compression in them induced by the sloping stay cables, and against the heavy wheel loads of the road traffic, would make them very expensive.)

Prefabrication also gives economy. The main span is often sub-divided into about 8 m long units. Each unit is prefabricated in a fabrication workshop and then shipped progressively to the construction site. (The fabrication workshop is usually built in the waterfront to facilitate launching of the units.) (Fig. 4.39, 4.40)

5.2 Erection of the Main Span

The main span is erected by loading each pre-fabricated deck unit onto a barge, towing the barge out to the correct location and then lifting the unit off the barge and up to its final position, using special cranes mounted on the part-completed deck above. (Each crane is large steel beam cantilevered out over the water and bolted down onto the deck.) Once it has been erected and aligned exactly, the steel web plates are bolted together by high strength friction grip bolts and the gap in the
Concrete slabs is filled with concrete around the projecting and overlapping reinforcing bars. *(Fig. 4.41)*

### 5.3 The Stay cables and staying (Fig. 4.42 - 4.45)

Each stay cable is made up of about 50 to more than a hundred strands (seven wires). They are made up on site from drums of wire strand rather than being delivered as complete factory produced stays. This process results in a lower overall cost.

Cable stayed bridges often accomplished with balanced cantilever method in which the deck segments on both sides of the bridge pylon are installed simultaneously. Alternatively, the side span can be constructed prior to the main span by the other method.

During the alignment and jointing of the unit just lifted to the already erected main span deck, the new stay cables are prepared for fixing to the new unit and for fixing back to the corresponding location on the opposite span. When the concrete completing the gap had cured sufficiently, normally after four days, the stay cables are tensioned. The next erection cycle can then be started by moving cranes forward, tied to the newly completed deck, …… and so on.
6. **Suspension Bridges (Fig. 4.46)**

The suspension bridge is currently the only solution for spans in excess of 600 m and is competitive for spans down to 300 m. The components of a suspension bridge are

1. Bridge Pylons
2. Anchorages
3. Main cables
4. Suspenders
5. Bridge deck

6.1 **Bridge Pylon (Fig. 4.47, 4.48)**

A bridge pylon may be made of steel or reinforced concrete. A cable saddle is installed on the top of the pylon to support the main cable.

6.2 **The Anchorage (Fig. 4.49)**

An anchorage is very massive concrete block at which the end of the main cable is securely anchored.

6.3 **The Main Cable and the Suspenders**

The overall diameter of the main cable may be over 1 m. Clearly, a cable of this size cannot be delivered and strung from anchorage to anchorage across the tower tops in one piece. *(Fig. 4.50)*

The cable may be installed strand by strand. Each strand is taken across the sea by barge and then lifted to tower top. The strands are then finally compressed and clamped together to form the main cable.

Alternatively, the main cable can be installed by aerial spinning method *(Fig. 4.51, 4.52)*. The initial strands were taken across the sea channel by barge and lifted to the tower top. Later strands were placed by ‘high lining’ based on the previously installed strands. Main cable of Tsing Ma Bridge, for example, is divided into 97
strands each composed of 368 high tensile steel wires (Fig. 4.53). Each cable was further compacted into a circular shape and bound with temporary strapping. Cast steel cable bands are then fitted, clamped into position by tightening bolts (Fig. 4.54, 4.55). The cable bands were placed at about 20m interval, which served also as the support for the suspender cable that hanged the bridge deck underneath (Fig. 4.56, 4.57).

6.4 The Bridge Deck (Fig. 4.58, 4.59, 4.60)

The most common method of forming the deck for a suspension bridge is by joining prefabricated steel truss segments. Each segment is prefabricated in workshop and transported by barge to right beneath the main cable. It is then lifted up and hung by the suspenders. Segment to segment is jointed by welding and bolting and eventually a continuous deck is formed.
7 Bridge Bearings

Highway structures and bridges flex, expand and contract. Bearings are provided to enable such movements to take place without causing damage to the structures.

Functions of Bridge bearings:

a. even transmission of vertical loads from superstructure to substructure and avoid stress concentration

b. accommodation of horizontal movements and rotations

c. better performance for dynamic load

7.1 Typical Bridge Bearings (Fig. 4.61)

<table>
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<tr>
<th>Bearing Type</th>
<th>Function Description</th>
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<tr>
<td>Rocker Bearing</td>
<td>Permit rotation about one or more axes but prevent translational movement.</td>
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<tr>
<td>Plane Sliding Bearing</td>
<td>Permit translation</td>
</tr>
<tr>
<td>Curved Surface Sliding Bearing</td>
<td>Curved surface may be cylindrical or spherical for uniaxial or multi-axial rotations respectively, and provide restrain against translation.</td>
</tr>
<tr>
<td>Elastomeric Bearing</td>
<td>Limited translational and rotational movement is accommodated by shear in the elastomer and the variation in compressive strain across the elastomer respectively.</td>
</tr>
<tr>
<td>Pot Bearing</td>
<td>Permit rotation about vertical axis but not permit translation.</td>
</tr>
</tbody>
</table>

Sometimes two or more bearings are used in conjunction to give a greater degree of freedom of movement for the bridge.
8 Expansion joints (Fig. 4.62)

Highway structures undergo dimensional changes as a result of temperature changes, shrinkage, creep and the application of prestress. Expansion joints are used to accommodate such dimensional changes.
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