(B) Preliminary Structural Design Report
of Flyover at Itten Road in Salalah City
at Governorate of Dhofar

Introduction:

This part is concerned with the preliminary structural design of the bridge at Itten road. It covers the codes and standards to be adopted, the loads to be considered, the structural analysis and load combinations, the proposed columns locations, the alternative structural systems and comparisons including typical cross sections as well as general details and considerations to be taken into account.

1. **Codes and standards:**

   The bridge, ramps, and retaining walls are designed in accordance with the provisions of the design code AASHTO LRFD bridge Design Specifications issued by the American Association of State Highway and Transportation (year 2007). If precast segmental method is used, then design should be in accordance with the provisions of AASHTO Guide Specifications for Design and construction of Segmental Concrete Bridge, 2nd Edition.

   For some specialized aspects of design not covered in the above mentioned codes, the following standards and codes can be used:

   - ACI 318 – (by American Concrete Institute), edition of 2011.
   - British Standard Institution, B5 5400, steel, concrete and composite bridges, latest edition
   - Eurocode standards issued by the European Committee on Standardizion (CEN), in particular:
     - EN 1990 Euro code 0: Basis of Structural Design.
     - EN 1991 Euro code 1: Action on Structural.
     - EN 1992 Euro code 2: Design of Concrete Structures.
     - EN 1993 Euro code 3: Design of Steel Structures.
     - EN 1994 Euro code 4: Design of Composite Steel and concrete Structures.
     - EN 1997 Euro code 7: Geotechnical Design.
     - EN 1998 Euro code 8: Design of Steel Structures for Earthquake Resistance.

2. **Loads:**

The following types and magnitudes of loads are to be considered:

2.1 Permanent Loads:

2.1.1 Dead loads; the unit weight of materials to be used for dead loads shall be as follows:

- Reinforced and prestressed concrete 25 KN/m^3
- Structural steel 78.5 KN/m^3

2.1.2 Superimposed dead load shall be the weight of all materials forming loads on the structure that are not structural elements. This includes the wearing surface, parapets and railing.

- Asphalt wearing course (120 mm shall be assumed for design 23 KN/m^3)
- The actual weight and position of all known or provisional utilities crossing shall be considered.

2.1.3 Erection loads in final state are the effects resulting from the method of erection which remain locked into the structure in the final state. These shall be included in all load combinations.

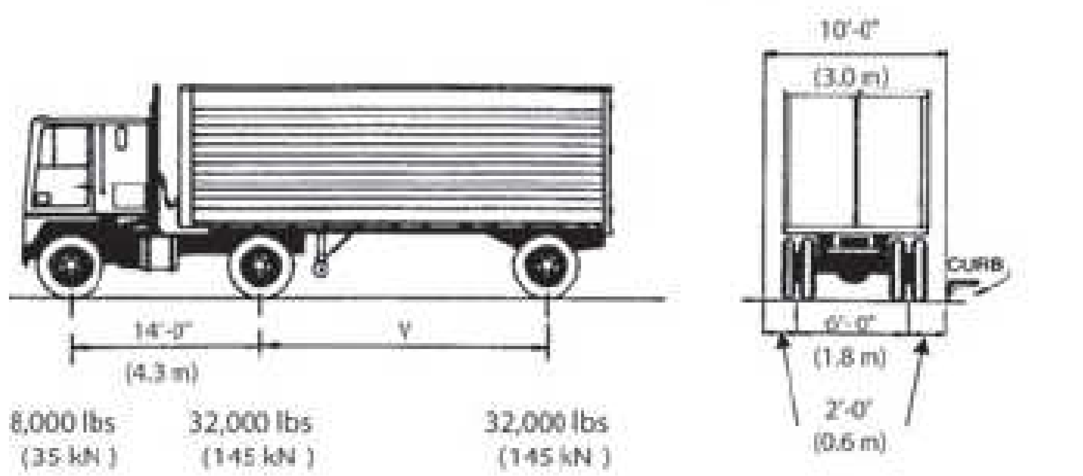
2.1.4 Prestressing load effects are those effects resulting from the application of prestressing loads to the structures as follows:

- PP: Primary effect (applied forces).
- PS: Secondary effect (restraint of deformation).

2.2 Live Loads:

- Vehicular live loading on the roadway of bridges consists of a combination of the design truck or design tandem applied simultaneously with the design lane load whichever gives the larger effect on the bridge.

- For negative moment between inflection points, 90 % of the effect of two design trucks spaced at a minimum of 1500 mm combined with 90 % of the design lane load are applied on the bridge. The above mentioned loads are shown in figure (1).



These sketches illustrate the AASHTO-approved live loading specifications for standard H20 and HS20 trucks.
Source: AASHTO Standard Specifications for Highway Bridges.

FIGURE (1) -A

Application Of Live Load

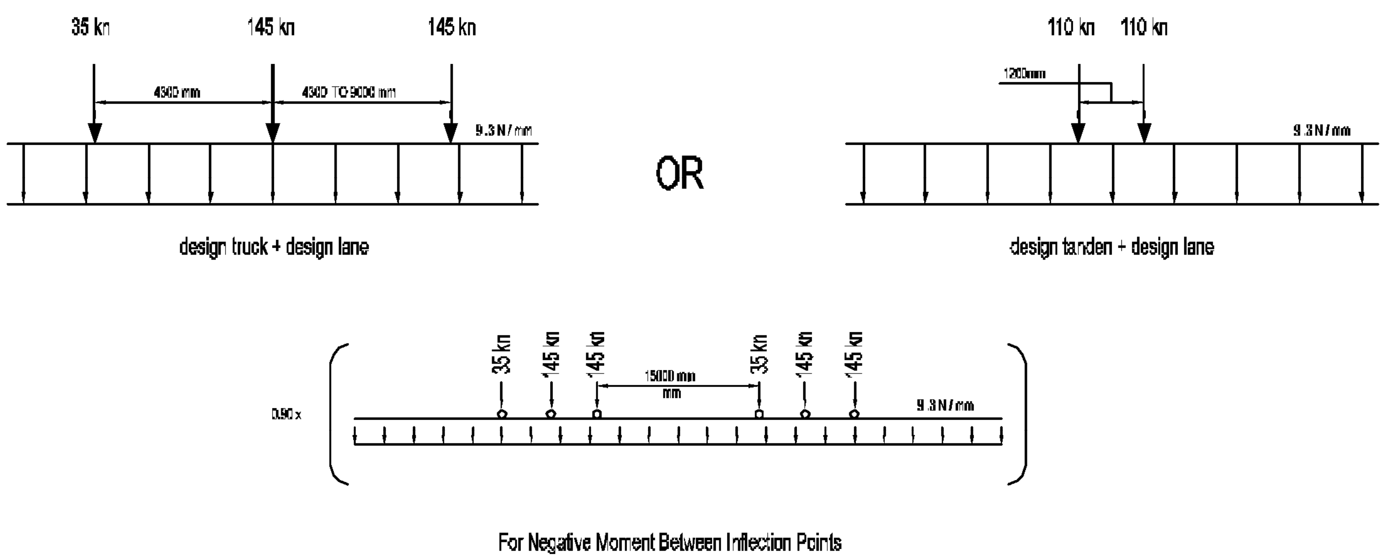


FIGURE (1)–B

- Pedestrian live load on highway bridge sidewalks are to be applied according to AASHTO LRFD.

- Other live load effects on highway bridges shall follow the relevant articles of AASHTO LRFD.
  - Dynamic load allowance.
  - Centrifugal forces (if any).
  - Braking forces.
  - Vehicular collision force.

2.3 Wind Loads:

For wind loads on the structure (bridge itself) or on the live load (vehicle), the provisions of AASHTO LRFD are adopted with base wind velocity 160 km/h.

2.4 Earthquake Loading:

The bridge is to be designed to withstand safely the 475-year return period earthquake. The forces are specified in the Omani Code. The response spectrum adopted is shown in figure (2) indicating the coefficients to be taken in Salalah area. The full design is in accordance with AASHTO LRFD articles.

ELASTIC RESPONSE SPECTRUM

$$S_{AE}(T) = 0.4 S_{SD} + 0.6 \frac{S_{SD}}{T_o} T \qquad (T_o \le T)$$

$$S_{AE}(T) = S_{SD} \qquad (T_o \le T \le T_S)$$

$$S_{AE}(T) = \frac{S_{1D}}{T} \qquad (T_S \le T \le T_L)$$

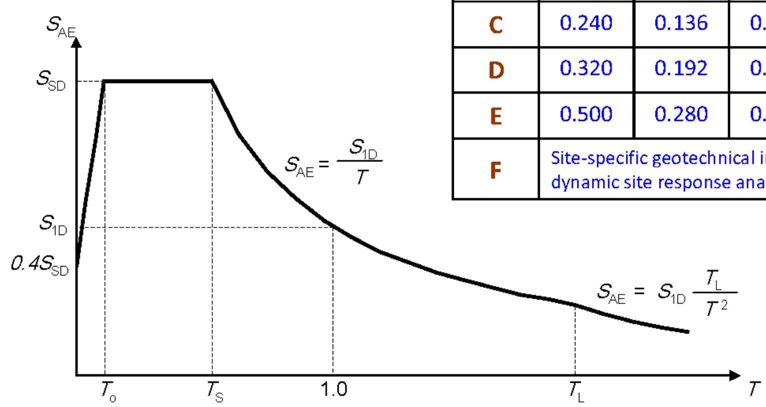
$$S_{AE}(T) = \frac{S_{1D} T_L}{T^2} \qquad (T_L \le T)$$

$$T_S = \frac{S_{1D}}{S_{SD}}$$

$$T_o = 0.2 T_S$$

Short period and 1.0 second elastic spectral accelerations

Local Soil Class	Seismic Zone: Zone 1 Muscat, Sohar, Diba, Khasab		Seismic Zone: Zone 2 Nizwa, Sur, Salalah	
	S_{SD} / g	S_{1D} / g	S_{SD} / g	S_{1D} /g
A	0.160	0.064	0.080	0.032
B	0.200	0.080	0.100	0.040
C	0.240	0.136	0.120	0.068
D	0.320	0.192	0.160	0.096
E	0.500	0.280	0.250	0.140
F	Site-specific geotechnical investigation and dynamic site response analysis required			



$T_L = 8$ s

FIGURE (2)

2.5 Earth Pressure:

The earth pressure forces and pressure on abutment walls and side walls of ramps or approaches are to be determined based on the materials to be used for backfilling and based on the provisions of AASHTO LRFD.

2.6 Force Effects Due to Superimposed Deformations:

2.6.1 In consideration of uniform temperature (TU), AASHTO LRFD to be adopted using the following values:

1. Temperature range for concrete bridges: +/- 30 deg C.
2. Temperature range for steel bridges: +40/-30 deg C.
3. The coefficient of thermal expansion shall be taken as 0.000011/deg C.
4. The design mean temperature shall be taken as 30 deg C

2.6.2 For incorporation of temperature gradient AASHTO LRFD articles, Zone 1 must be followed.

2.6.3 To determine the effects of creep and shrinkage, AASHTO LRFD Articles shall be followed, together with the recommendations of CEB-FIP MC90 for the assessment of creep and shrinkage strains.

2.6.4 The mean annual relative humidity assumed for the calculation of drying shrinkage and creep shall be taken as 60 % (humid climate).

2.6.5 The magnitude of differential settlement shall be determined on the basis of the soil investigation and the foundation type selected. AASHTO LRFD Articles shall be used as reference for the case of pile foundations. Unless the soil investigation report conclusively precludes possibility of any settlement, the cumulative effect of at least 25 mm differential settlement of individual foundations shall be considered (higher values if the report specifies so).

3. Load Combinations:

Different load combinations are considered for the bridge based on AASHTO LRFD and Omani Code provisions as follows:

- Five load combinations for strength limit state
- Four load combinations for serviceability limit state and two load combinations for the extreme event limit state.

All these load combinations are shown in figure (3). Only applicable load combinations are to be considered.

It should be noted that in Extreme Event load combination, the live load factor is 0.5 to reflect the low probability of the occurrence of the maximum vehicular live load and the extreme event (earthquake for example).

Load Combination / Limit State	DC DD DW EH EV ES EL	LL IM CE BR PL LS	WA	WS	WL	FR	TU CR SH	TG	SE	Use One of These at a Time			
										EQ	IC	CT	CV
STRENGTH-I	γ_p	1.75	1.00	–	–	1.00	0.50/1.20	γ_{TG}	γ_{SE}	–	–	–	–
STRENGTH-II	γ_p	1.35	1.00	–	–	1.00	0.50/1.20	γ_{TG}	γ_{SE}	–	–	–	–
STRENGTH-III	γ_p	–	1.00	1.40	–	1.00	0.50/1.20	γ_{TG}	γ_{SE}	–	–	–	–
STRENGTH-IV EH, EV, ES, DW	γ_p	–	1.00	–	–	1.00	0.50/1.20	–	–	–	–	–	–
DC ONLY	1.5												
STRENGTH-V	γ_p	1.35	1.00	0.40	0.40	1.00	0.50/1.20	γ_{TG}	γ_{SE}	–	–	–	–
EXTREME EVENT-I	γ_p	γ_{EQ}	1.00	–	–	1.00	–	–	–	1.00	–	–	–
EXTREME EVENT-II	γ_p	0.50	1.00	–	–	1.00	–	–	–	–	1.00	1.00	1.00
SERVICE-I	1.00	1.00	1.00	0.30	0.30	1.00	1.00/1.20	γ_{TG}	γ_{SE}	–	–	–	–
SERVICE-II	1.00	1.30	1.00	–	–	1.00	1.00/1.20	–	–	–	–	–	–
SERVICE-III	1.00	0.80	1.00	–	–	1.00	1.00/1.20	γ_{TG}	γ_{SE}	–	–	–	–
SERVICE-IV	1.00	–	1.00	0.70	–	1.00	1.00	–	1.00	–	–	–	–
FATIGUE-LL, IM & CE ONLY	–	0.75	–	–	–	–	–	–	–	–	–	–	–

For notes on γ_p, γ_{EQ}, γ_{TG} and γ_{SE}, refer to *LRFD Specifications*

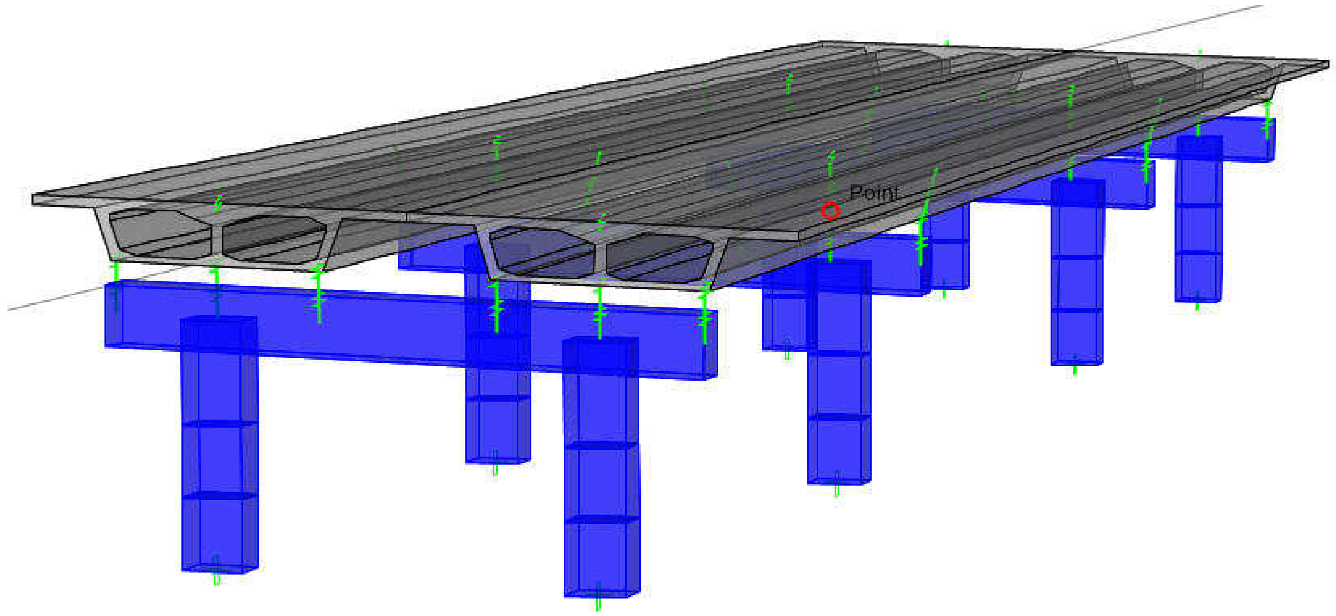
Type of Load	Load Factor	
	Maximum	Minimum
DC: Component and Attachments	1.25	0.90
DD: Downdrag	1.80	0.45
DW: Wearing Surfaces and Utilities	1.50	0.65
EH: Horizontal Earth Pressure		
• Active	1.50	0.90
• At-Rest	1.35	0.90
EL: Locked-in Erection Stresses	1.00	1.00
EV: Vertical Earth Pressure		
• Overall Stability	1.00	N/A
• Retaining Walls and Abutments	1.35	1.00
• Rigid Buried Structure	1.30	0.90
• Rigid Frames	1.35	0.90
• Flexible Buried Structures other than Metal Box Culverts	1.95	0.90
• Flexible Metal Box Culverts	1.50	0.90
ES: Earth Surcharge	1.50	0.75

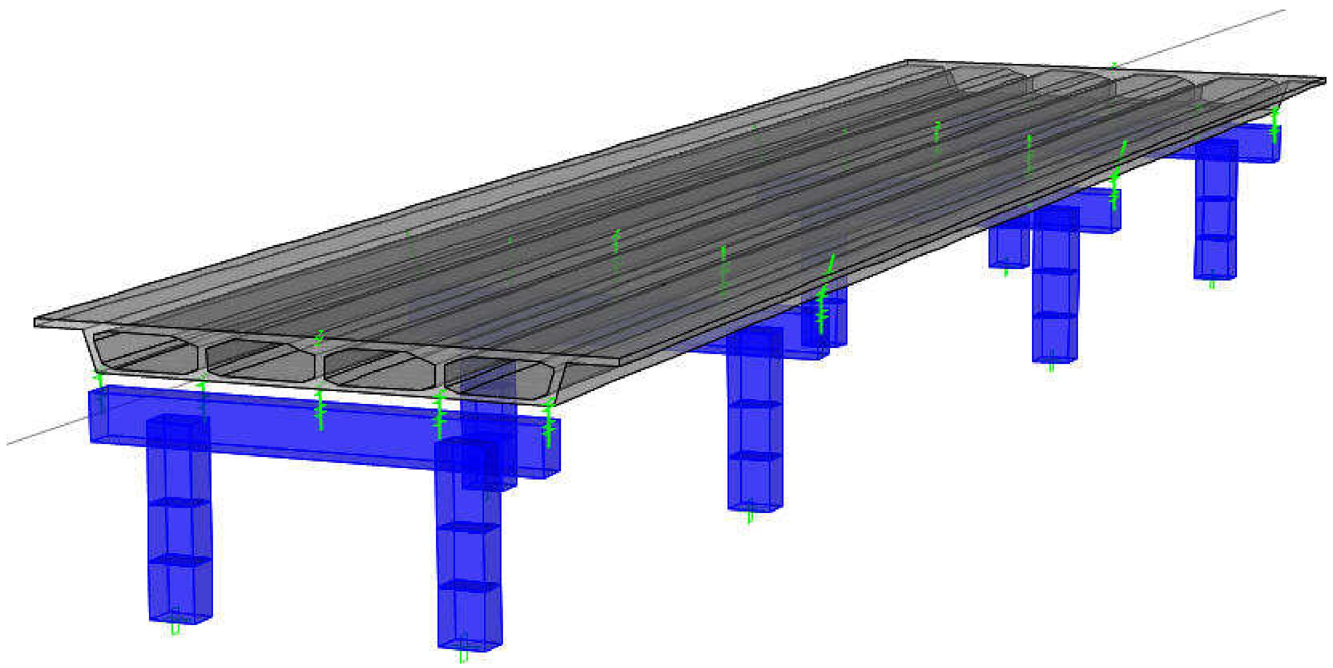
Figure (3)

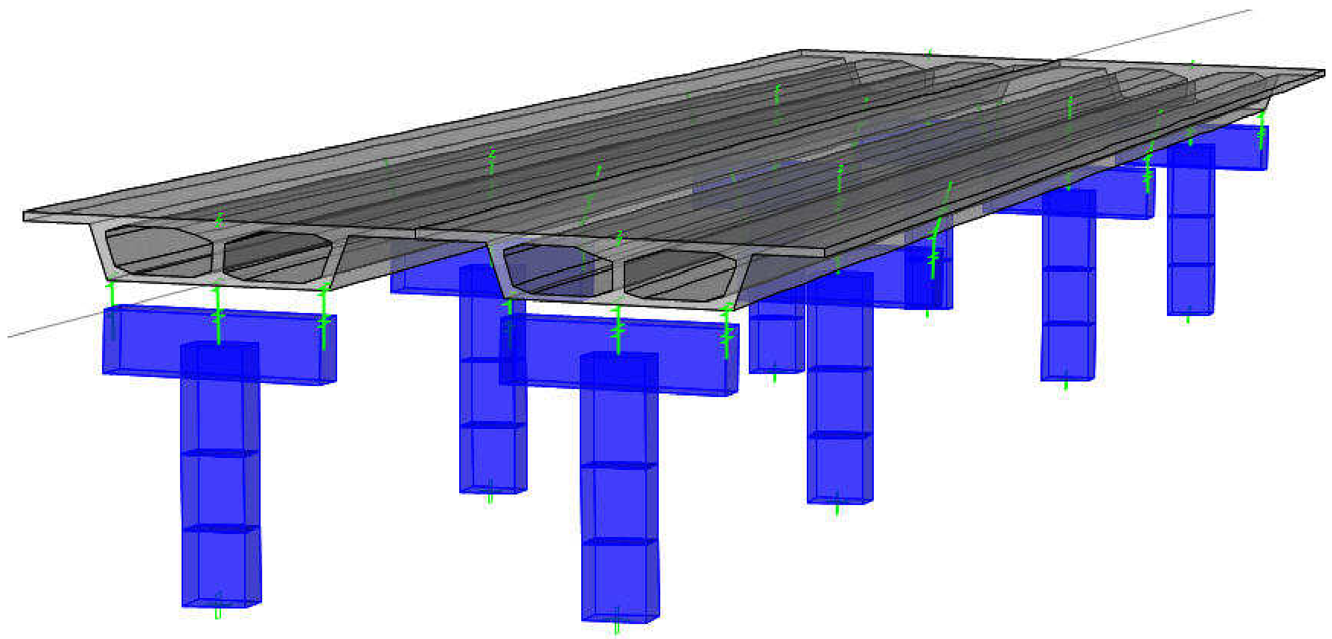
4. **<u>Structural Analysis:</u>**

General structural analysis programs (such as CSI Bridge) are used for the analysis of superstructure of the bridge. Grillage or 3-D models are to be applied based on the structural system to be used (box–girder or precast beams) and the supporting system for the super structure.

The bearings are to be modeled as linear springs with stiffness coefficients related to the type to be used. If super structure is integrated with columns, then the columns are modeled as frame elements. The cases of loading to be used are those to give maximum straining actions for the specified element. some analysis models for parts of the bridge are as shown.







Preliminary Design Alternatives for the Bridge:

Based on the bridge and roads alignment, the columns and abutments are chosen as shown in figure (4). The total length of the bridge is 220 ms from abutment at axis (1) to abutment at axis (8). The span of the bridge is 30 ms except for the two spans from axis (3) to axis (4) (28.5 ms) and from axis (4) to axis (5) (41.5 ms).

Different design alternatives are evaluated and a comparison is made to reach the most appropriate design.

Alternative (A) **:** **Precast Prestressed Concrete Beams**

For the 30 ms span (from axis (1) to (2) and from (2) to (3) and (6) to (7) and (7) to (8)), precast Prestressed concrete beams spaced at 2.0 ms intervals are used. The total depth of these beams is 140 cm (115 cm for the precast beam and 25 cm for the top cast in situ slab). These beams are supported on the abutments at axes (1) and (8) and on frames at axes (2), (3), (6), (7). This depth satisfies the minimum clearance requirements (5.5 ms) for the u-turns between axes ((1) , (2)) and ((7), (8)).

For spans between axes ((3), (4)) and ((5), (6)), the same system of precast prestressed concrete beams can be used.

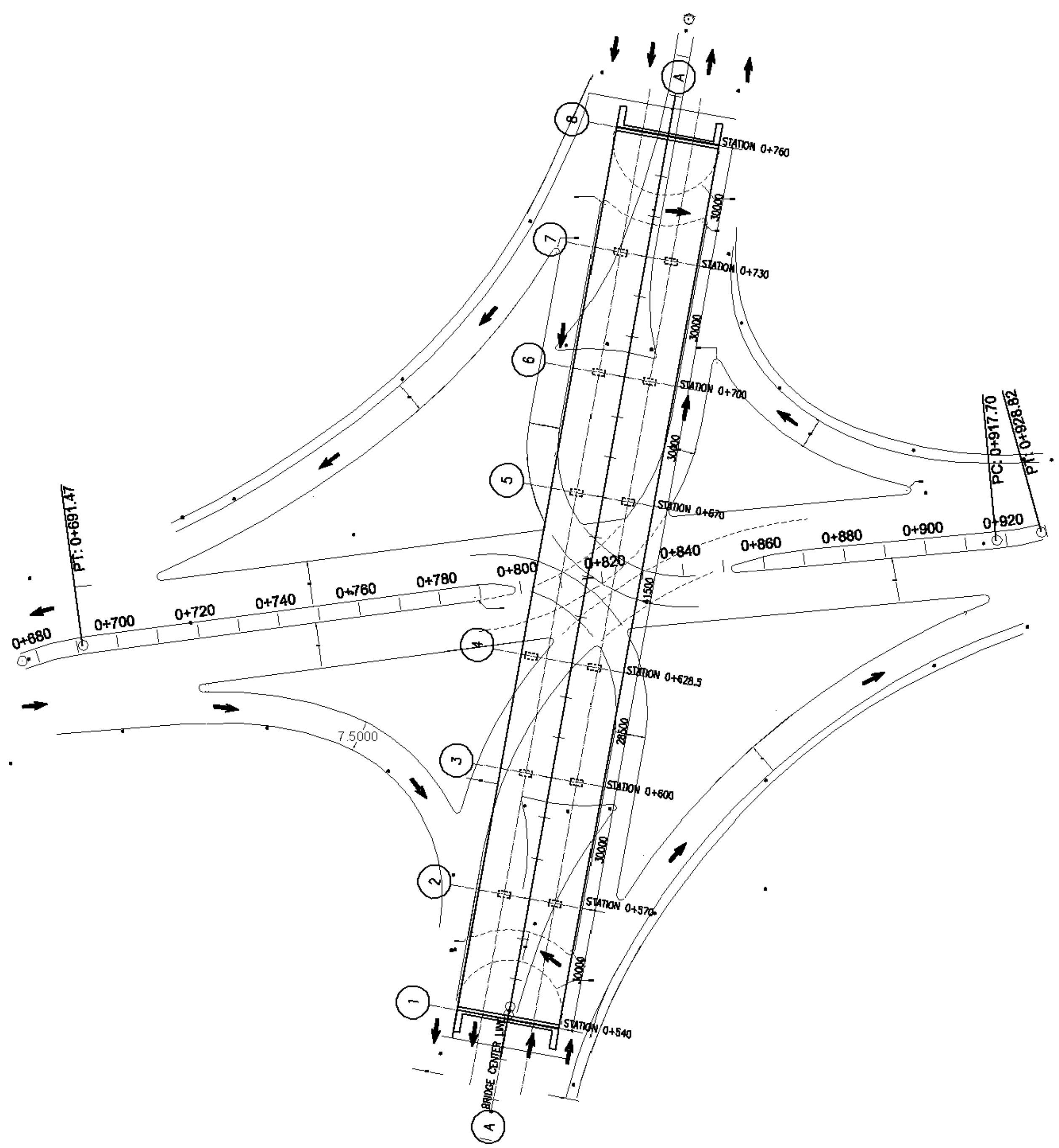


Figure (4)

For span between axes ((4) and (5)) (41.5 ms), if the same system is adopted, the total depth of the beams is 185 cm (160 cm precast beams plus 25 cm cast in situ slab). This depth satisfies the minimum clearance requirements for the main road under the bridge; however, the supporting frame having a depth of 235 cm will not satisfy the clearance requirements by about (45-50 cm)for the turns from or to the main road (at axes 4, 5). The system is shown schematically in figures (5) to (9). For this system, expansion joints (max 2 cm wide) are used at all axes from (1) to (8). In addition, each precast beam is supported on elastomeric bearing.

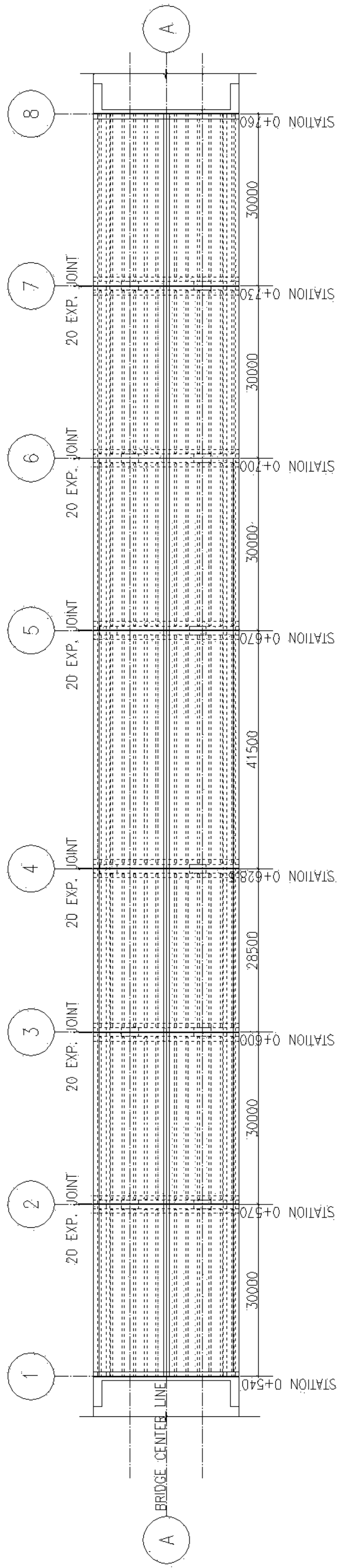


FIGURE 5
ALTERNATIVE A

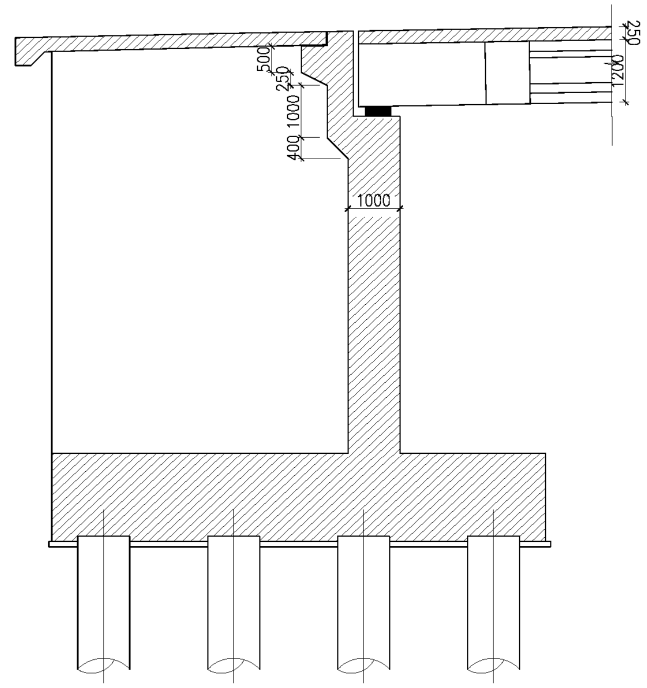


FIGURE 6
SECTION @ AXIS 1–1

ALTERNATIVE A

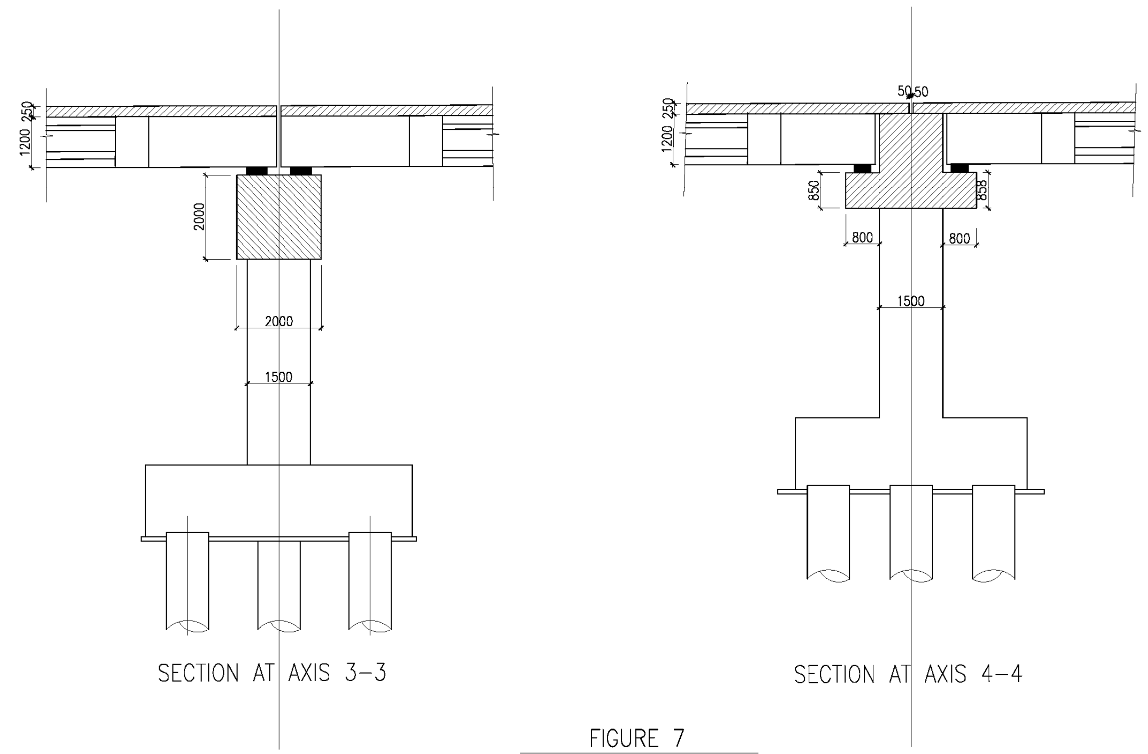


FIGURE 7
SECTIONS AT PIERS

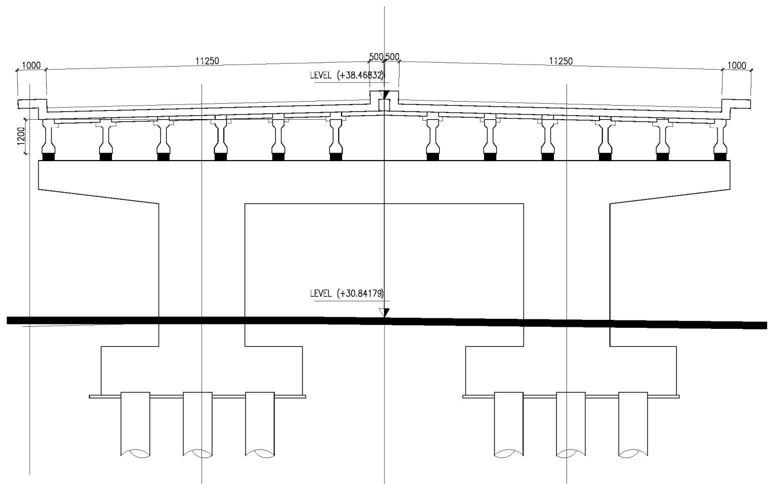


FIGURE 8 ALTERNATIVE A
SECTIONS @ AXIS 3-3

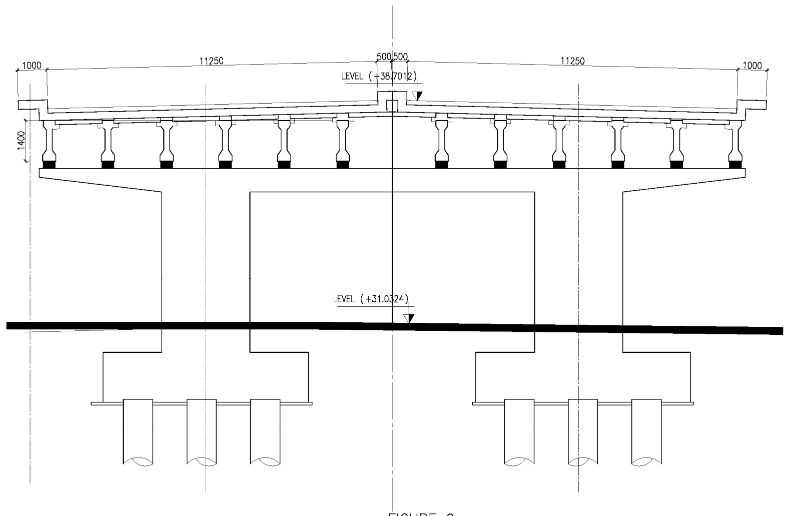


FIGURE 9 ALTERNATIVE A
SECTIONS @ AXIS 4-4

<u>Alternative (B)</u> : **<u>Box Girder Section</u>**

In this alternative, box-girder section is used. The depth of the box-girder is 2.0 ms for the long span between axes (4) and (5) and also for adjacent spans between axes (3, 4) and (5, 6). The depth for the adjacent spans is taken 2.0 ms also to account for the continuity requirements and moments. However, the other spans are to have a box-girder with only 1.5 ms depth. The box-girder is supported monolithically with the supporting columns at axes (3), (4), (5), and (6) while supported on frames on axes (2), (7) and on abutments at axes (1) and (8) through bearings. Haunched sections are used to connect between the 2.0 ms and 1.5 ms section. In this system two expansion joints (5 cm wide) are used at axes (1) and (8) only. This system satisfies clearance requirements throughout the bridge. The system is shown schematically in figures (10) to (14).

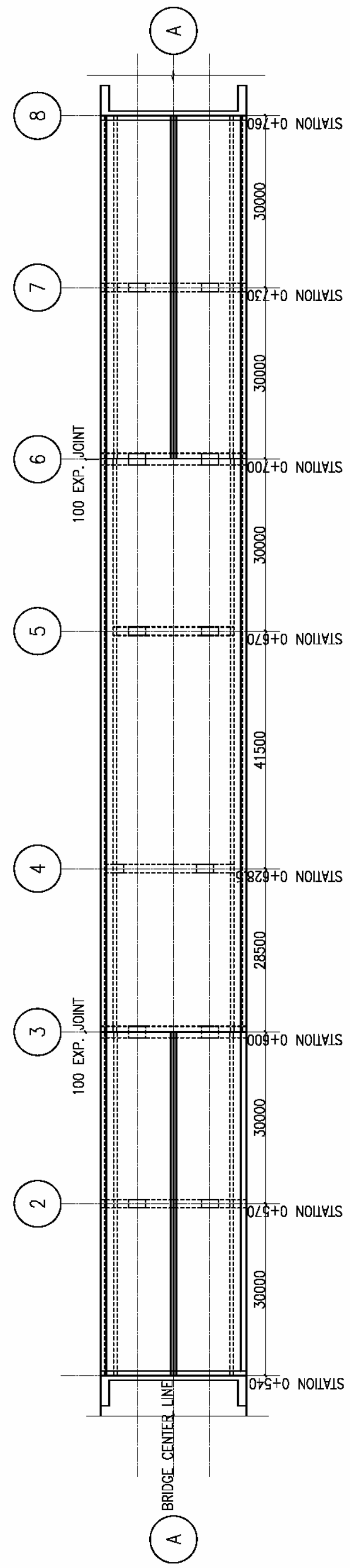


FIGURE 10
ALTERNATIVE B

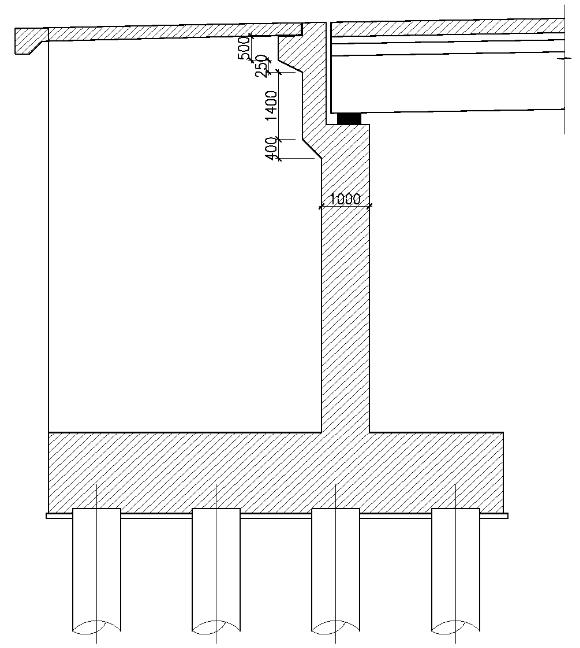


FIGURE 11
SECTION AT AXIS 1-1

ALTERNATIVE B

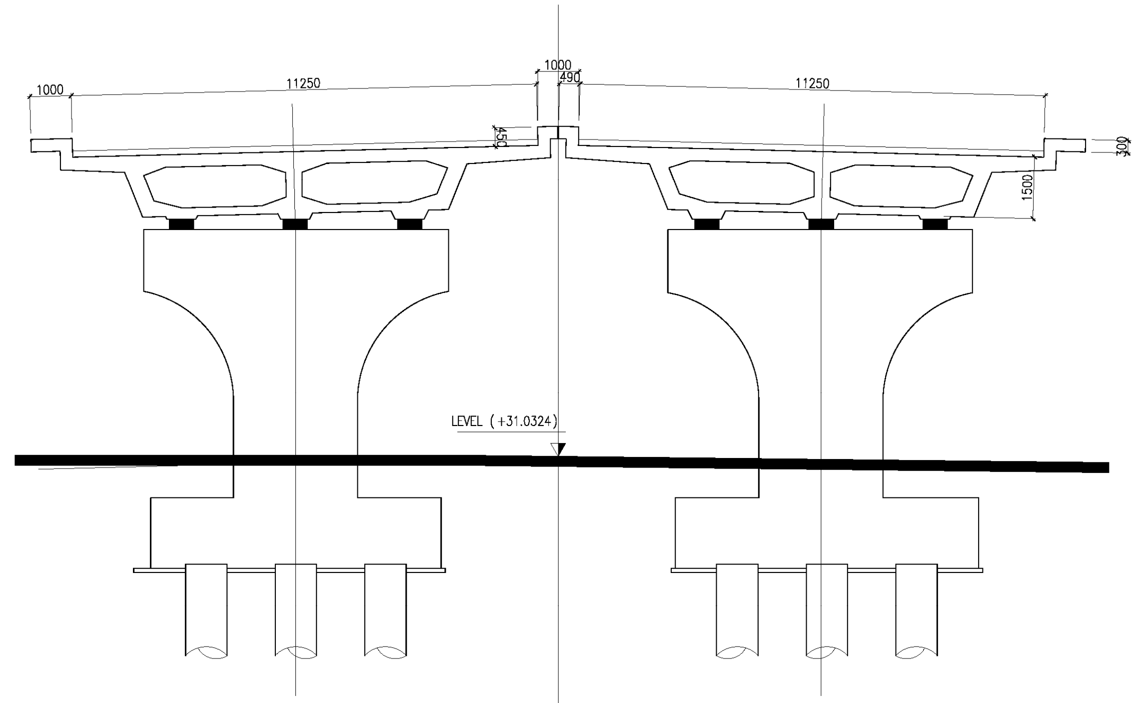
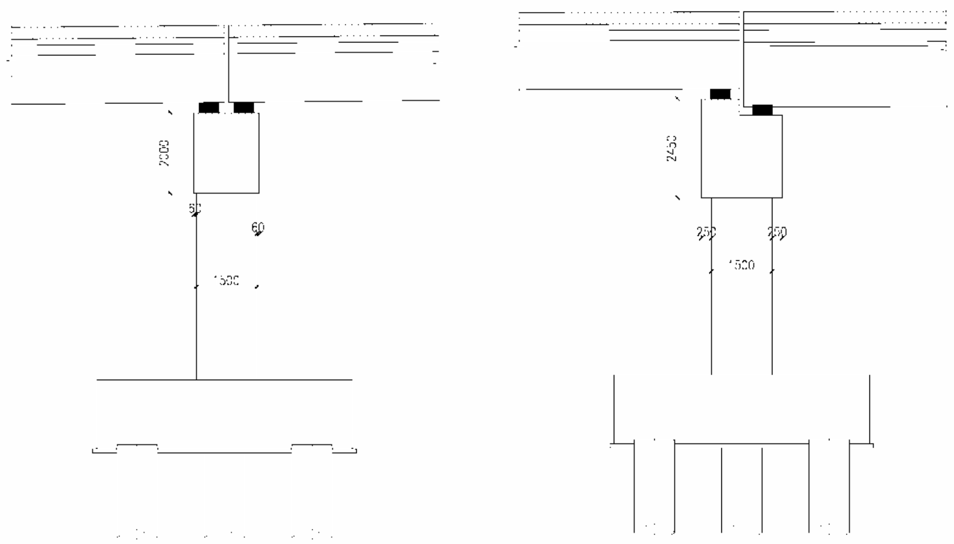


FIGURE 13
SECTION @ AXIS 2-2

ALTERNATIVE B



SECTION @ AXIS 2-2

SECTION @ AXIS 3-3

FIGURE 12
SECTION AT PIERS

ALTERNATIVE B

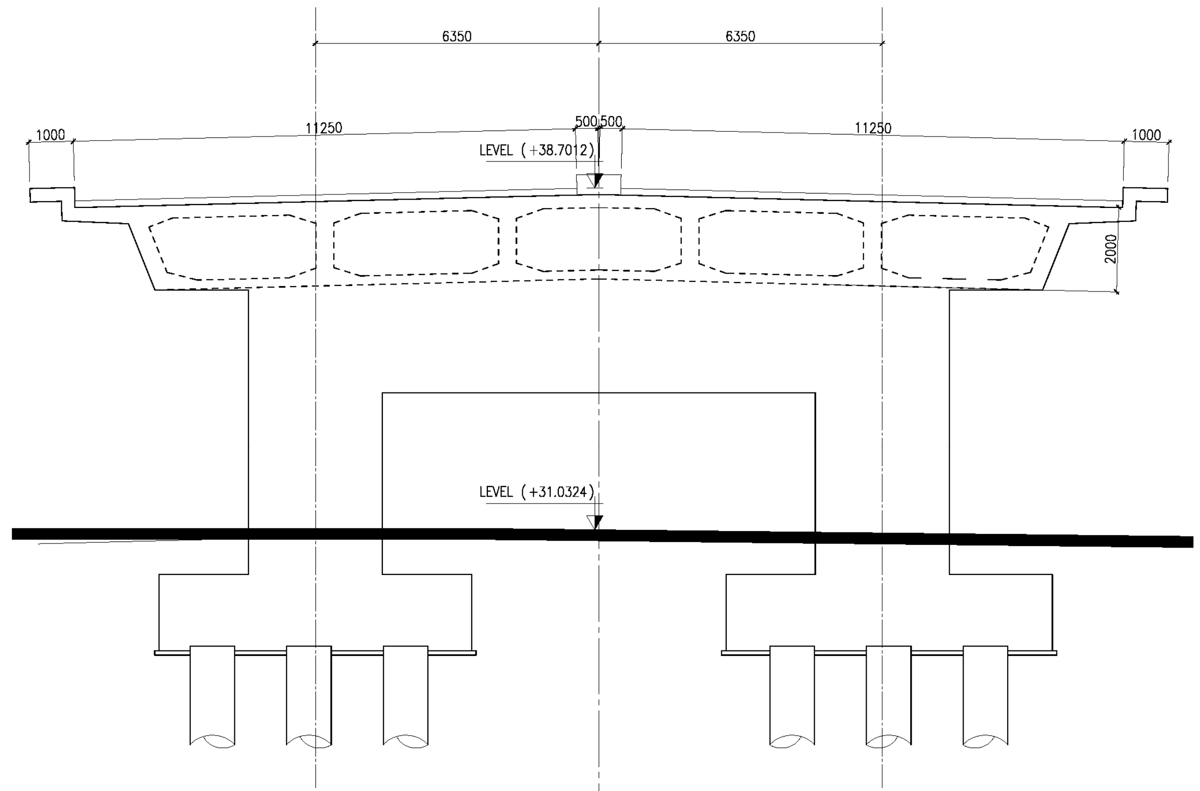


FIGURE 14
SECTION @ AXIS 5-5

ALTERNATIVE B

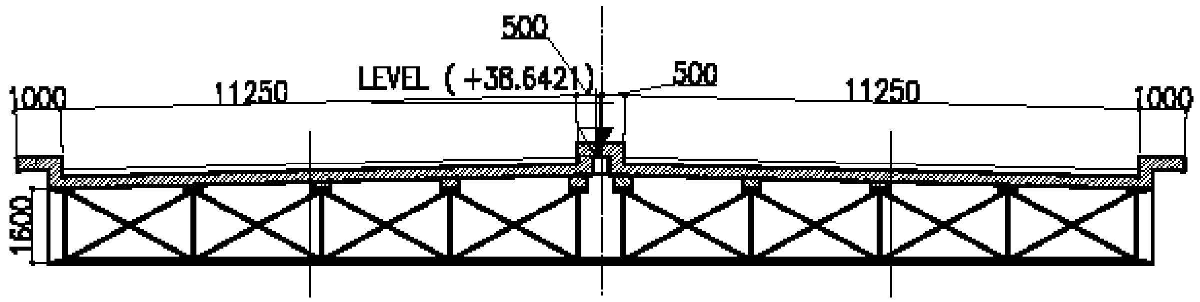
Comparison, Evaluation, and Recommendation

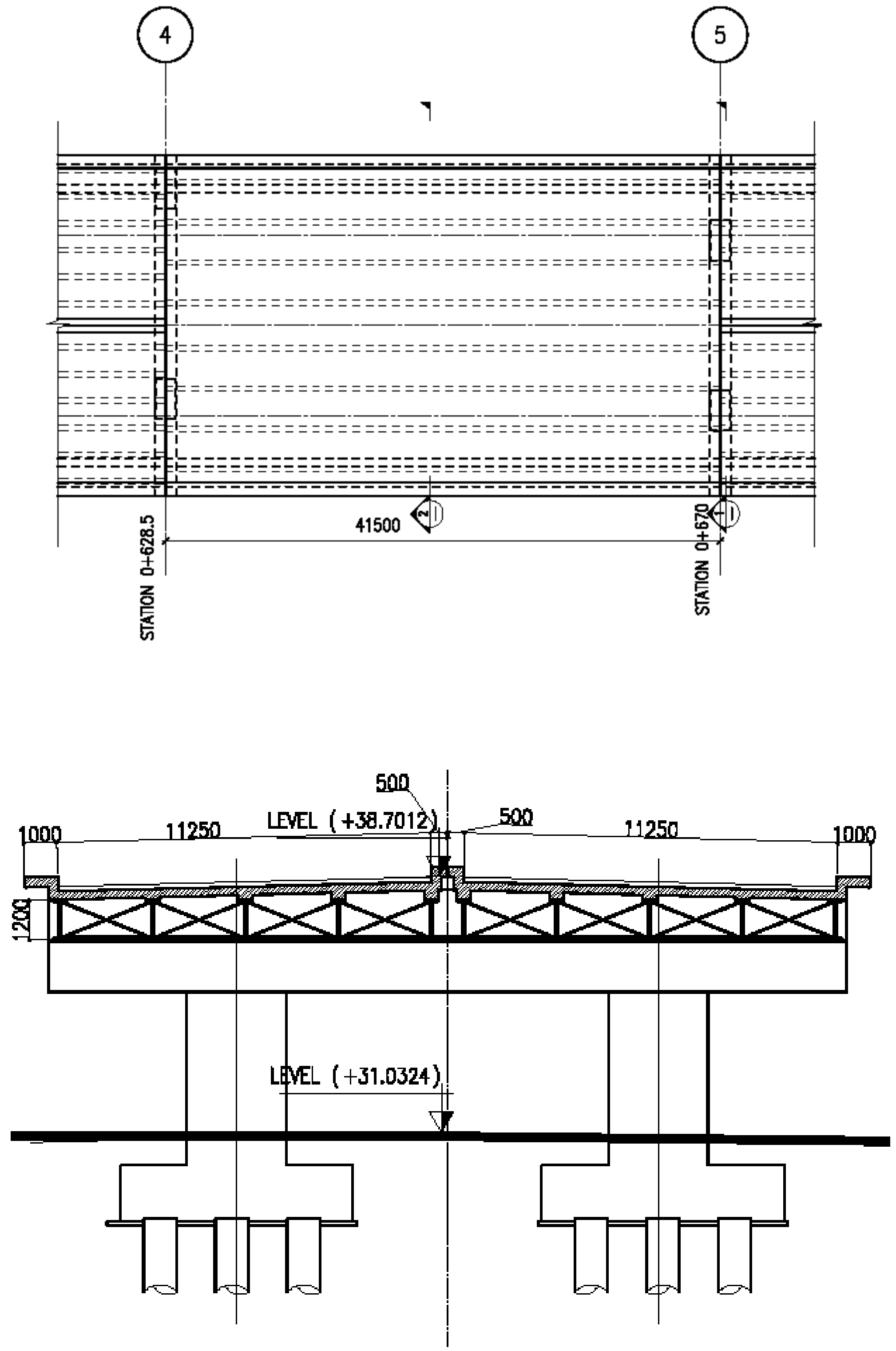
The above two alternatives are evaluated based or economy, ease and speed of construction, fulfilling clearance requirements and serviceability and maintenance.

For Alternative (A) (Precast Prestressed Beams), shuttering and scaffolding is needed only on the axes for columns and frame construction. No shuttering or scaffolding is needed between axes. The precast beams are placed on the frames at the axes and the top cast in situ slab can be cast without a need for scaffolding; fly shutters between precast beams (or precast slabs) can be used to support wet concrete. In addition, as the precast beams can be prepared during foundations, columns, and frame construction, the construction time can be reduced. On the other hand, for this system an expansion joint is needed at each axis and the number of elastomeric bearings is very large (2 for each beam); all this requires continuous monitoring. A system for maintenance and replacement of joints and bearings should be planned. An important issue also is the clearance requirement at axes (4) and (5) which requires revising of the levels of main road and turns under the bridge. This can be avoided if steel sections are used instead of the precast concrete beams (see figure (15)).

For alternative (B), the box-girder concrete bridge satisfies all clearance requirements. This system is also economic regarding material usage, in addition this system has no expansion joints except at axes (1) and (8), and the number of bearing is very few. This requires little maintenance and the need for replacing the bearings is much less than in alternative (A). However, this system requires planning to design the shuttering and scaffolding in order not to affect dramatically the flow of traffic during construction.

Mixing between the two system can be chosen. For example, the box girder system can be used for part from axis (3) to axis (6) while precast beam are to be used for outer spans ((1) to (3) and (6) to (8)).





SECTION 1 @ AXIS 5-5

FIGURE 15
ALTERNATIVE C

General Details:

The following details and considerations are to be taken into account for the detailed design of the bridge.

A. Abutments and Retaining walls:

The abutments at axes (1) and (8) are to be designed as reinforced concrete retaining walls. These walls are to support the end reactions of the bridge structural system through the bearings; in addition, they are subjected to earth pressure from backfilling materials of the approaches as well as from traffic load. These walls are subjected to vertical as well as heavy horizontal loads. Typical cross section is shown in figure (16). It should be noted that the height of the wall in more than 8 ms, hence, the thickness of these R.C walls is about 100 cm.

For the side retaining walls of the approaches, two alternatives are evaluated: (1) reinforced concrete cantilever retaining wall or (2) key-stone reinforced earth retaining wall. Preliminary designs for the two options was carried out. As the clear height above ground level to top of wall is more than 7-7.5 ms, the thickness of the cantilever reinforced concrete wall is large and the foundation for that wall requires long projected thick parts, and due to very high bending moments, the safety of this wall requires huge amount of reinforcement. All these facts make this option very uneconomical compared to the option of key-stone reinforced earth wall. In this option, reinforcing geogird sheets are used to reinforce the soil at designed specified intervals and soil is well compacted under very restrict quality control system. The geogird sheets are supported and fixed at the outer key stone wall (as shown in figure (17)). The option of key-stone reinforced earth wall gives also flexibility for colouring and architectural forms as shown in figure (18). Hence, it is recommended to use this system in our case.

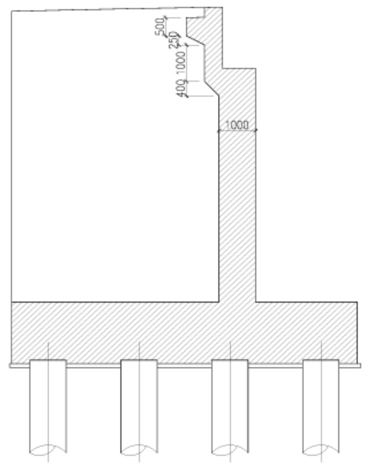
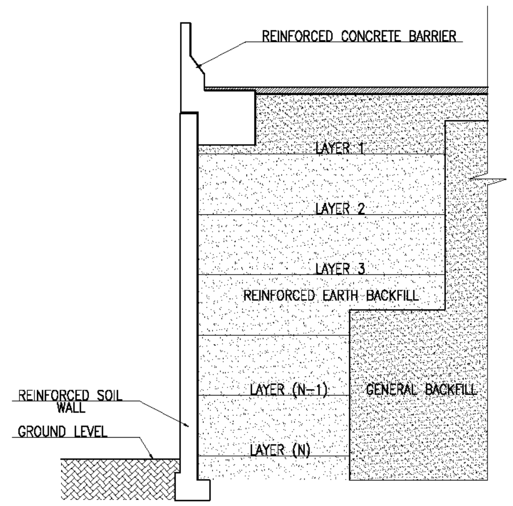


FIGURE 16
RETAINING WALL



SECTION 1-1

FIGURE 17
MECHANICAL STABILIZED WALL

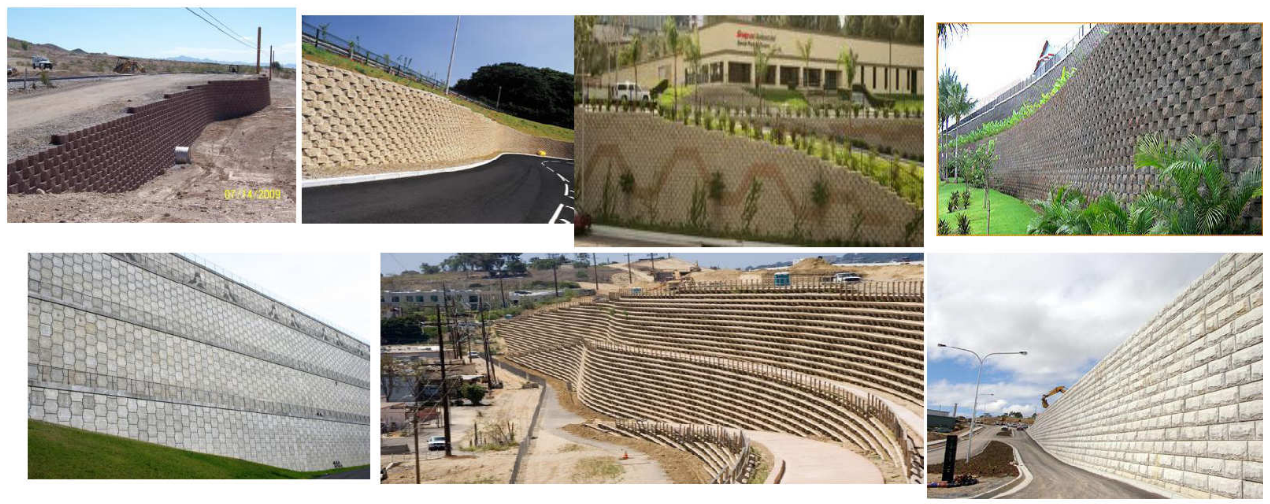


Figure (18)

Samples for key stone walls

B. Approach Slab:

for the smooth transition from reinforced concrete bridge structure to the asphalt road at the approaches, an approaches reinforced concrete slab 6-10 ms long is used. This slab is supported on the abutment from one side and on the well compacted earth along its length (as shown in figure (19)). This slab provides smooth driving from bridge to approach.

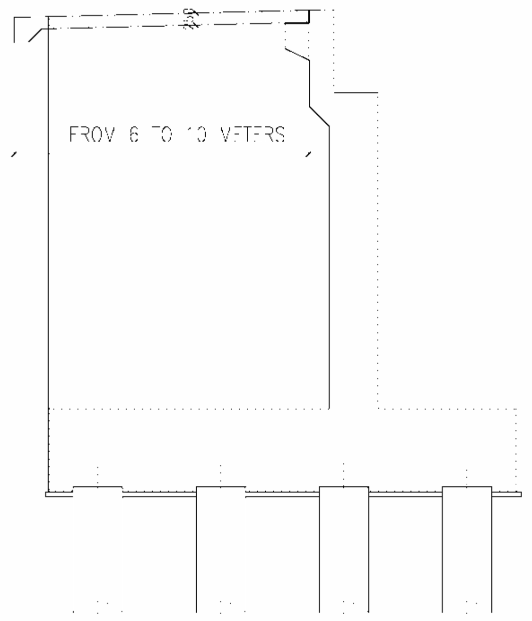


FIGURE 19
APPROACH SLAB

C. Bearings:

Depending on the structural system to be finally adopted, different types of bearings can be used:

C-1 Elastomeric Bearings: These bearings provide controlled movements in X, Y, and Z directions. They consist of elastomer layers reinforced with steel plates. The thickness, number of layers, and dimensions are determined based on the applied forces (see figure (20)).

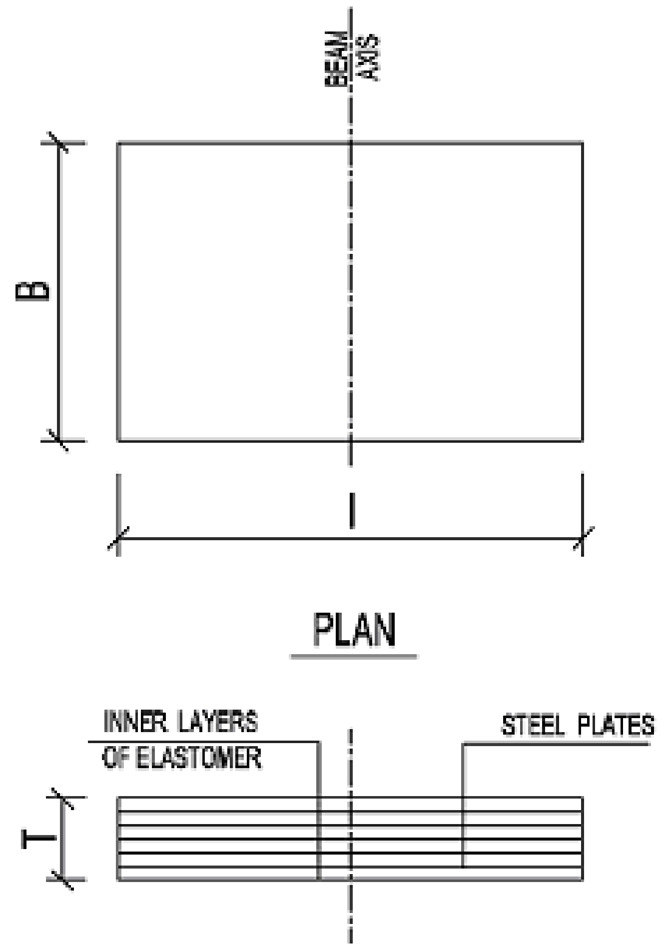


FIGURE 20
ELASTOMERIC BEARINGS

C-2 Pot Bearings: These bearings consist of pot and steel piston with electrometric pad with PTFE sliding surface (as shown is figure (21)). These bearings can provide movement in one horizontal direction only or two directions in addition to the vertical direction or prevent movement totally in the horizontal direction. The choice for fixed directions and also the final thickness and dimensions depends on the models used for the bridge analysis in additions to the applied straining actions.

For all bearings, the procedure for replacement is to be detailed in the final design documents.

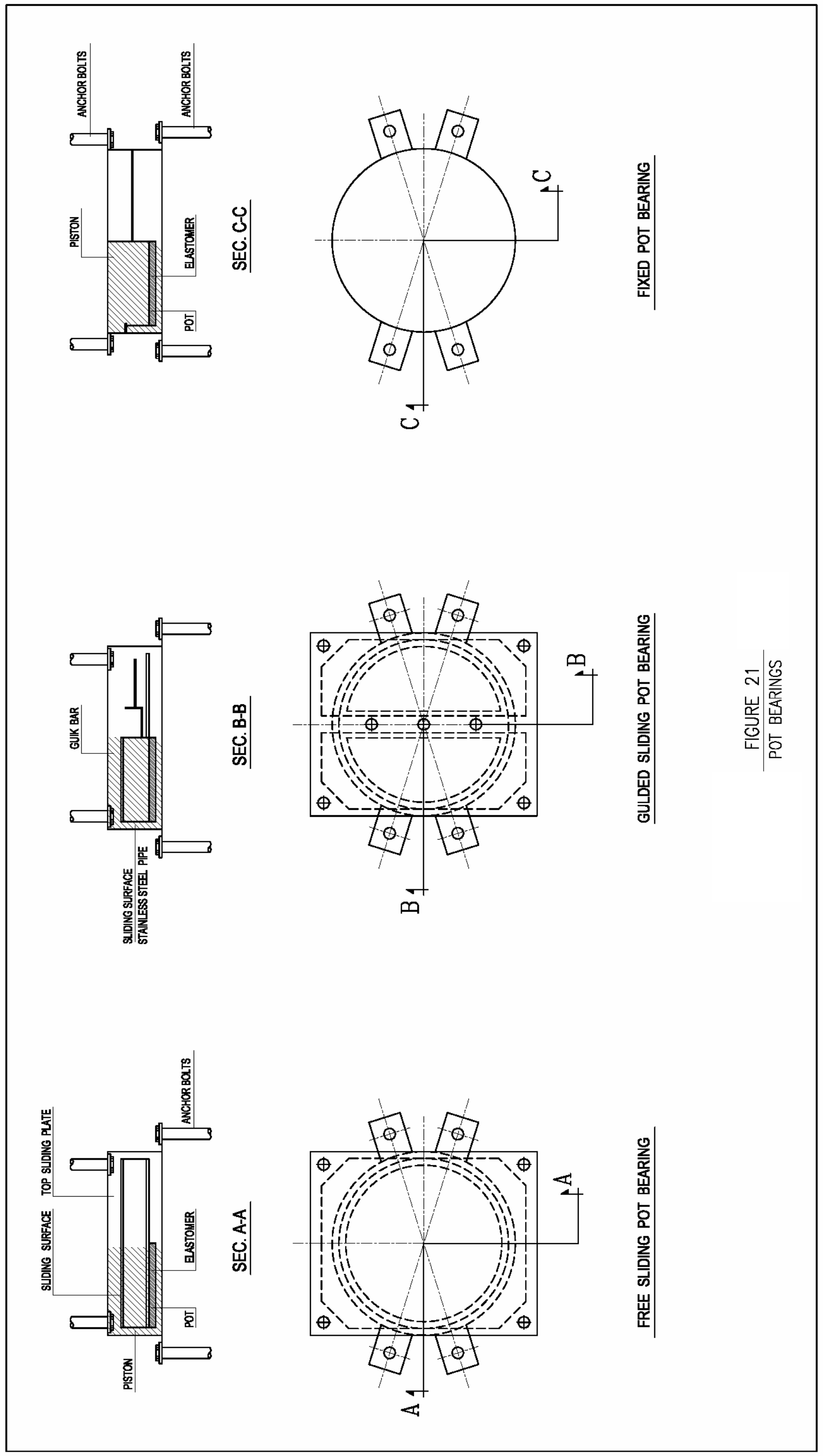


FIGURE 21
POT BEARINGS

D. Expansion Joints:

Designers are encouraged to reduce the number of expansion joints in bridge decks as possible to reduce their effect on durability and maintenance.

There are many types of expansion joints that can be used for bridges:

- Electrometric sealed joints.
- Modular joints using neoprene box or band sections.
- Metallic finger joints.
- Asphaltic plug joint

Asphaltic plug joints as shown in figure (22) are used for a range of movement up to ± 25 mm. They are suitable when the distance between expansion joints is up to 50 m.

Elastomeric joints, as shown in figure (23), are used for a range of movement up to ± 165 mm. They are suitable at the end of bridges up to 600 m long with no intermediate expansion joints.

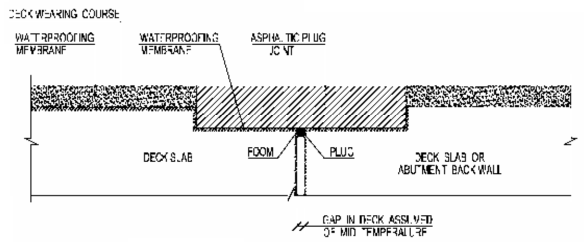


FIGURE 22
ASPHALTIC PLUG

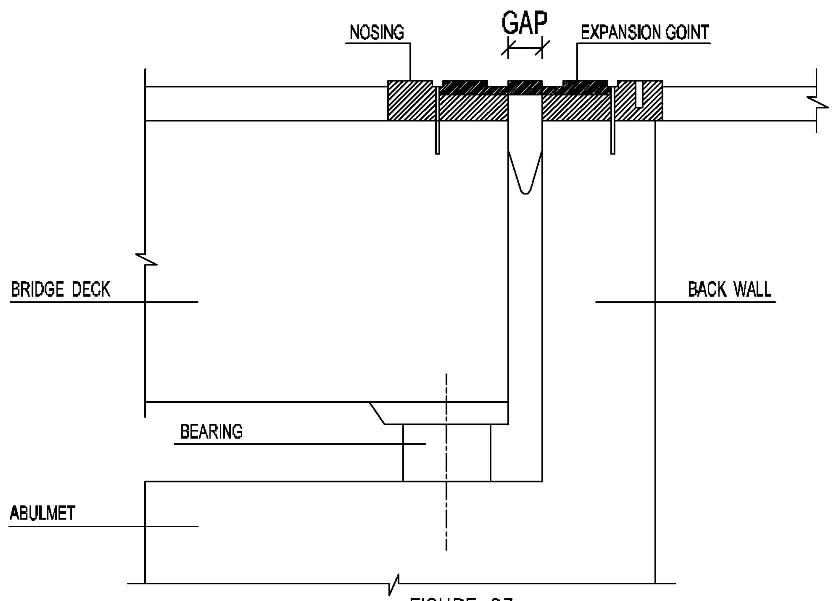


FIGURE 23
ELASTOMERIC JOINTS

E. Maintenance and Inspection:

Al Parts of the structures should be easily accessible for inspection particularly the following elements:

- Steel bride superstructure.
- Bearings.
- Expansion joints.
- Prestressing anchorages and anchor zones.

End and intermediate diaphragms in concrete box girder bridges should have an opening of an absolute minimum of 600 * 100 mm to allow for passage of inspectors inside the box. The inside of the box shall be accessible from the outside through openings in the deck soffit and/or the abutment behind the end diaphragms. The openings should be free of any utility pipes or ducts.

Where there is a joint between the abutment and the superstructure, a gallery shall be provided between the abutment back wall and the superstructure end diaphragms to allow for inspection of the bearings, expansion joint, end diaphragm, prestressing anchorage, steel diaphragm.

Al bearings shall be replaceable. The design shall show the location of the jacking points on the substructure and superstructure drawings, The design of the bridge superstructure shall account for the amount of lifting necessary for the bearing replacement.

F. Traffic Barriers and Handrail:

As the bridge has no pedestrian walkways, the safety barriers shown in figure (24) should be provided. The design forces shall be in accordance with AASHTO LRFD Section 13, Appendix A.

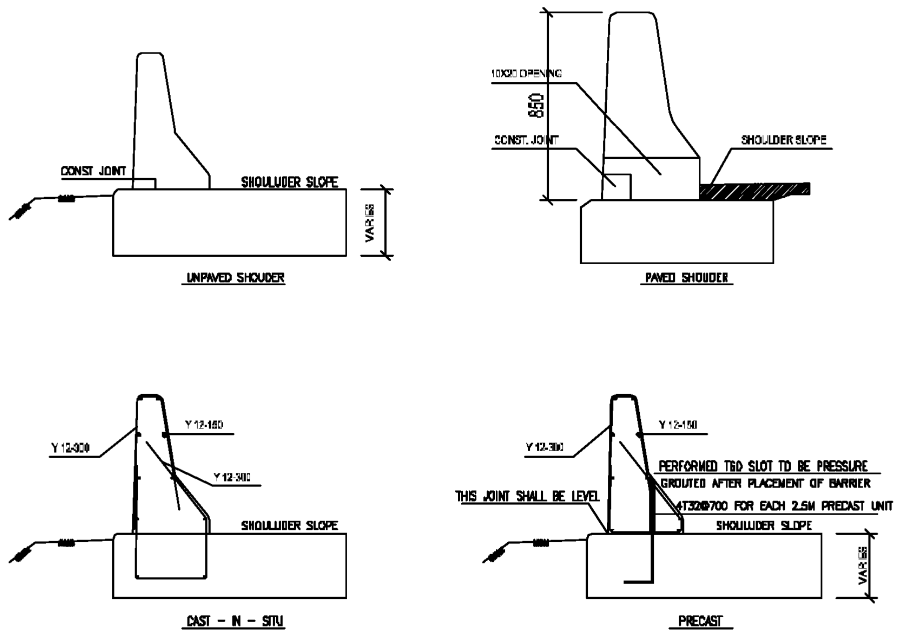


FIGURE 24
BARRIERS

Architectural Considerations:

As bridges last for a long life span, they should be esthetically appealing. They should combine tradition and modernity. They should reflect Omani characteristics as well as the technical era of their construction.

Although each structure shall have individuality, but for the same project or along the same corridor, structures should have continuity in forms and features. The above consideration will be reflected in the architectural presentation of the proposed bridge.