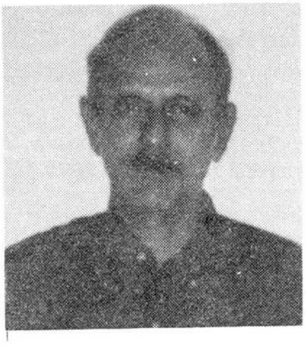
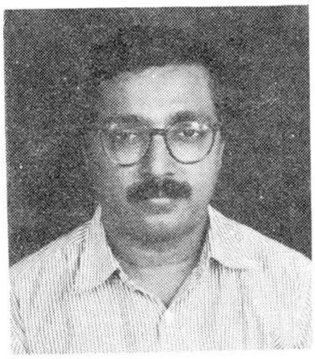
Design of foundation for multispan arch bridge over river Sungai Dinding

DESIGN OF FOUNDATION FOR MULTISPAN ARCH BRIDGE OVER RIVER SUNGAI DINDING





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SUMMARY

The bridge over river Sungai Dinding is being constructed north of Lumut, in the district of Manjung, Perak, Malaysia, which is about 250 Km north of Kuala Lumpur. The bridge is a part of a 13.5 Km long new dual two lane roadway project which crosses three major rivers namely Sungai Dinding, Sungai Sitiawan and Sungai Tebok Raja Samalon. The bridge over Sungai Dinding is a multispan arched deck with varying span lengths. The arches will be constructed by tied cantilevering. Once completed, it will be a landmark structure of Malaysia.

The ground conditions at the river bed are poor comprising loose sand for depths of 10 to 15 meters underlain by medium dense silty sand. The length of the piles are of the order of 40m to 65m. Precast pre-tensioned hollow spun piles of high strength concrete are employed for ground conditions that are acidic in nature. Barge impact governs the design of foundations. Raker piles are proposed for counter-acting the large lateral forces.

The paper highlights the basic design philosophy, loading & salient design & detailing features of the foundations of this bridge. The designs are based on British codes and requirements of JKA, Malaysia.

1.0 INTRODUCTION

The new Sungai Dinding Bridge under construction is the longest of the three bridges of the contract with a total length of 1246 m between abutments, Fig 1. The main river portion of the bridge is designed as reinforced concrete multispan spandrel arches with spans varying from 45 m to 90 m. The multispan arched deck with reducing span lengths from middle of the river towards the shore combined with vertical curvature of the decking presents a visually arresting architectural form. The approaches on either side of the arch spans are provided with 4-span continuous reinforced concrete box girders with intermediate spans of 45 m and end spans of 38 m.

The bridge is supported on 600 mm and 800 mm dia hollow pretensioned concrete spun piles, 40-65 meters deep passing through poor sub-strata.

The owner for the bridge is JKR, the Malaysian Government department responsible for transport. The turnkey contractor for the project is Panzana Lankhorst J/V. Engineering consultants are Robert Benaim & Associates in association with HMS Perunding (Malaysia). Proof Consultancy involving completely independent analysis and design is being done by HSS Integrated Sdn Bhd (Malaysia). Tandon Consultants Pvt Ltd is providing specialist technical support for structural analysis and design of the project to HSS Integrated Sdn Bhd (Malaysia).

2.0 SUB-SOIL CHARACTERISTICS

The site investigation indicates that the geology of the area is characterised by completely decomposed granite (CDG) some 60m below bed level. The CDG is a dense to very dense residual soil described as "Silty sand with some gravel". The alluvium soil above the CDG comprises medium dense silty sands of approximately 40 m depth. The upper-most strata consists of loose sand and silt with layers of soft clay. Fig 1 depicts a compiled sub-strata profile along the bridge.

The chemical tests conducted on soil / water samples at various depths indicate that the same are acidic in some stretches.

3.0 SPAN ARRANGEMENT & SALIENT STRUCTURAL DETAILS

3.1 Span Arrangement

The span arrangement for the main bridge over river comprises 13 reinforced concrete arches. The navigational width requiring maintenance dredging is restricted to the central 3 spans, Fig 1. The geometry of the central 90m span was derived from the requirement of 18m high and 40m wide navigational clearance. The arch has a span/rise ratio of 4:1. The bridge is on a vertical curvature with the maximum gradient of 4% at the approaches. The overall depth of the hollow box arch section is kept constant at 2.25m for the central arch and is gradually reduced to 1.6m at the end arch, Fig 2. The depth of the approach span box girders has been maintained constant at 3.0m, Fig 3. The overall width of 13.88m incorporates a 12.0m clear carriageway and 600mm walkway on either side.

The span arrangements have been optimized from structural and aesthetic considerations and arrangements made for facilitating inspection in service conditions.

A 1.0m wide opening in the top slab is provided for access into the arch box section. The bearings and soffit of the composite deck are accessed from the top of the arches. The interior of the approach span box girders are accessed from the abutments.

3.2 Bearing Arrangement

Pot Bearings are proposed to be used for the bridge. Bearings are detailed so that they can be easily replaceable by jacking up the bridge. A 10 mm vertical differential movement of the deck at individual pier position is allowed for in the design under SLS conditions.

3.3 Foundation Arrangement

Precast pre-tensioned spun concrete piles have been provided for the foundations. The choice of this type of pile was quite obvious, taking into account the long term durability, ground conditions, topography, loading & general availability. Several Malaysian companies manufacture precast spun piles and therefore their utilisation works out fairly economical.

The arch spans are supported on 800mm dia piles while the approach spans are supported on 600 mm dia piles.

The larger diameter piles are provided for river foundations where vertical loads are high in addition to barge impact loads and out-of-balance forces associated with the arch form. 600mm diameter piles are provided for the less heavily loaded approach spans, which are also not subjected to such large lateral loads. Raker piles are required to resist forces and movements caused due to out-of-balance arch action, barge impact, traction, braking, and the forces due to progressive collapse condition. A combination of raker and vertical piles have therefore been used for this project. A maximum rake of 1 in 4 has been used. Rake is provided in different direction to cater for the forces due to barge impact. For foundations of approach spans, rake is provided only along the direction of traffic.

3.4 Construction Methodology for the Bridge

For approach spans, piling will be carried out using conventional methods. Temporary sheet piling will be necessary to keep the piling rig & the working platform in dry condition. For river spans, the piles are driven by using hydraulic hammer mounted on a piling frame. In river, piling is being carried out from barges.

For off-shore pile caps, upon completion of the pile installation, sheet piles are driven around the installed piles to form a cofferdam. The purpose of sheet pile cofferdam is to enable casting of concrete pile cap in dry conditions. On-shore elevated pile caps soffit formwork is supported either using temporary scaffolding from ground or using steel clamps.

The reinforced concrete box arches are constructed by using stayed cast-in-situ cantilever construction technique using travelling formwork. The travelling formwork is designed for casting upto 5m segment lengths. The steel frame structure with attached forms, platforms and safety railings weighs about 50 tonnes. Fig. 5 & 6 shows the construction stages for the arched deck which is self explanatory.

The spandrels are cast-in-situ over arch using steel moulds with push-pull props for stability.

The steel I-beams for composite deck will be fabricated off-site and delivered by trailer to the job-site. The concrete decking will be formed with proprietary formwork system specially suited for this type of construction.

4.0 DESIGN CRITERIA FOR FOUNDATION

4.1 Design Loads (Table 1)

a) **Dead Loads and Superimposed Dead Loads**
Unit Wt. for concrete is taken as 24.5 kN/m^3. Surfacing load of 1.2 kN/m^2 , Verge loading of 2.4 kN/m at each edge and Parapet load of 7.5 kN/m at each edge has been connsidered.

b) **Highway and Pedestrian Live Loads**
The British code loading of full HA and 45 units of HB loading in combinations described in BD 37/88 for four 3.0m lanes has been considered for the 12.0m carriageway. For the 600mm wide raised verges 5.0 kN/m^2 pedestrian loading has been accounted for.

c) **Loading from Barge Impact**
Barges of 5000 (DWT) travelling at 5.0 knots have been considered for evaluating forces on foundations in navigation portion. In the remaining foundations, loads of 50% of those applicable to the navigation channel, have been considered. Reference nay be made to Fig 7 for details.

d) **River Flow**

Maximum current velocity considered is 1.0m/s (2.0 knots) for the full water depth for SLS check increased by 50% under ULS conditions.

e) **Floating Debris Loading**

For all river piers, a nominal force of 100 kN at SLS increased by 50% under ULS, representing debris loading, is applied in any direction at pile cap level and combined with the force due to river flow.

f) **Seismic Loading**

Records show no significant seismic activity in the immediate area of the project. However, a nominal horizontal load equivalent to 0.03g as a ULS load case has also been considered.

g) **Wind Loading**

Forces due to wind are determined in accordance with BD 37/88 with an assumed mean hourly wind speed of 30 m/s.

h) **Differential Settlement**

The structure has been designed for a long term differential settlement of 10 mm between adjacent foundations.

i) **Construction Stage Loading**

Construction sequence of a typical arch and that of the river spans from one end are shown in Figs 4 and 5. These are duly accounted for in the design.

j) **Temperature Loading**

Forces and movements due to temperature are determined from the following:-
Temperature Range = 20^{0}C – 40 ^{0}C
Mean Temperature = 30^{0} C

Forces and stresses arising from differential temperature are determined in accordance with BD 37/88.

k) **Accidental Loading due to Progressive Collapse.**

The detailed design for the superstructure of the river spans includes a check against progressive collapse in the event of a foundation or arch being removed by barge impact. For foundation removal it is assumed that the two connecting spans will be demolished and that the adjacent spans suffer damage requiring extensive repair. For the removal of an arch it is assumed that extensive remedial works will be required on the adjacent foundations and adjacent spans.

4.2 Load Factors & Load Combinations

For loads which are covered in BS codes, the load combinations are as per BD 37/88 and therefore not reproduced. However load combinations under barge impact, progressive collapse, and seismic. which are not covered in BD 37/88. Table 1 gives the load factors considered.

4.3 Design Criteria, Assumptions for Pile Foundation

The factors of safety considered for Ultimate Skin Friction (SF) and for Ultimate End Bearing (EB) in the design are:

a) Normal Service Conditions:

- Vertical Load carrying capacity under compression at SLS : (SF/2.0 + EB/3.0) or (SF+EB)/2.5 whichever is smaller
- Vertical Load carrying capacity under compression at ULS : (SF+EB)/1.5
- Tension at SLS : (SF)/3.0
- Tension at ULS : (SF)/2.0

b) Barge Impact & Progressive Collapse

- Tension at ULS : (SF+EB)/1.2
- Tension at ULS : (SF)/1.2

For establishing the load carrying capacities, trial piles were installed and tested at selected locations. Due to the high load carrying capacities of piles and the practical difficulties of testing inclined piles. the trial piles were kept vertical. Also due to presence of large numbers of raker piles, it was found difficult to carry out load test on working piles. In view of this, the factors of safety given above were increased by 10% to ensure that sufficient capacities of the working piles are attained.

Based on load testing of trial piles, the following capacities were arrived at:

- For 800mm dia Spun piles :
  - Nominal Working Load : 300 tonnes, compression
  - Maximum Accidental Load : 550 tonnes, compression
    265 tonnes, Tension
- For 600mm dia Spun piles :
  - Nominal Working Load : 200 tonnes, compression
  - Maximum Accidental Load : 500 tonnes, compression

4.4 Pile Particulars

The piles were manufactured by the Malaysian company, ICP.
For pre-tensioned piles, due to the use of spun technology in concreting, very high strength can be achieved with low w/c ratio. Concrete grade used & the particulars of the mix used are as follows :

- Characteristic Strength : 78.5 MPa
- Water / Cement Ratio : 0.32
- Workability (Slump) : 40 mm
- Cement Type : OPC
- Mix Proportions
  - Cement Content : 500 Kg
  - Water Content : 160 litres
  - Fine Aggregate Content : 650 Kg
  - Coarse Aggregate Content : 1100 Kg
  - Admixture, Mighty 150 : 7.0 Kg
- Designed Density of concrete : 2417 Kg/m^3

5.0 DESIGN AND DETAILING OF FOUNDATION

The foundation is designed for loads and moments as per the loading criteria discussed earlier. For the purpose of load assessment on pile group, the entire structure consisting of 13 arches, from expansion joint to expansion joint, is modelled as a 3D-space frame . The pile group support is modelled as springs with stifnesses in all the six directions. The pile group stiffness is calculated by analysing each pile group separately using a 3D-space frame model. In order to simulate the variations in the ground profile, two extreme conditions has been considered while fixing the depth of fixity of pile.. Free length of pile is maximum when maximum dredging & maximum scour is considered simultaneously. Free length of pile is minimum when no dredging and no scour is considered. Fig 6 indicates the two conditions.

The capacity of each pile is checked for the combined axial load and bending forces resulting from the load cases being considered including necessary allowances due to slenderness.

For the design of pile, there are three critical sections, namely:

a) Pile section in running length
b) Joints of piles to make up the required length
c) Junctions of pile-pile cap interface

For evaluating (a), the normal SLS and ULS checks are performed
For evaluating (b), the spun piles are joined by full penetration weld of size 12mm and 14mm for 600mm and 800mm piles respectively. For the purpose of capacity calculation, 5mm corrosion of weld has been assumed.
For evaluating (c), the two alternative types of details indicated in Fig 8 are considered.

6.0 CONCLUSION

Poor sub-soil for a large depth coupled with large lateral loads due to arched deck and forces of possible barge impact posed a challenge for the foundation designers. Prestressed concrete spun piles proved to be an effective solution for the foundations of this bridge. Use of spun technology in concreting at factory environment ensured that very high strength could be achieved with low w/c ratio.

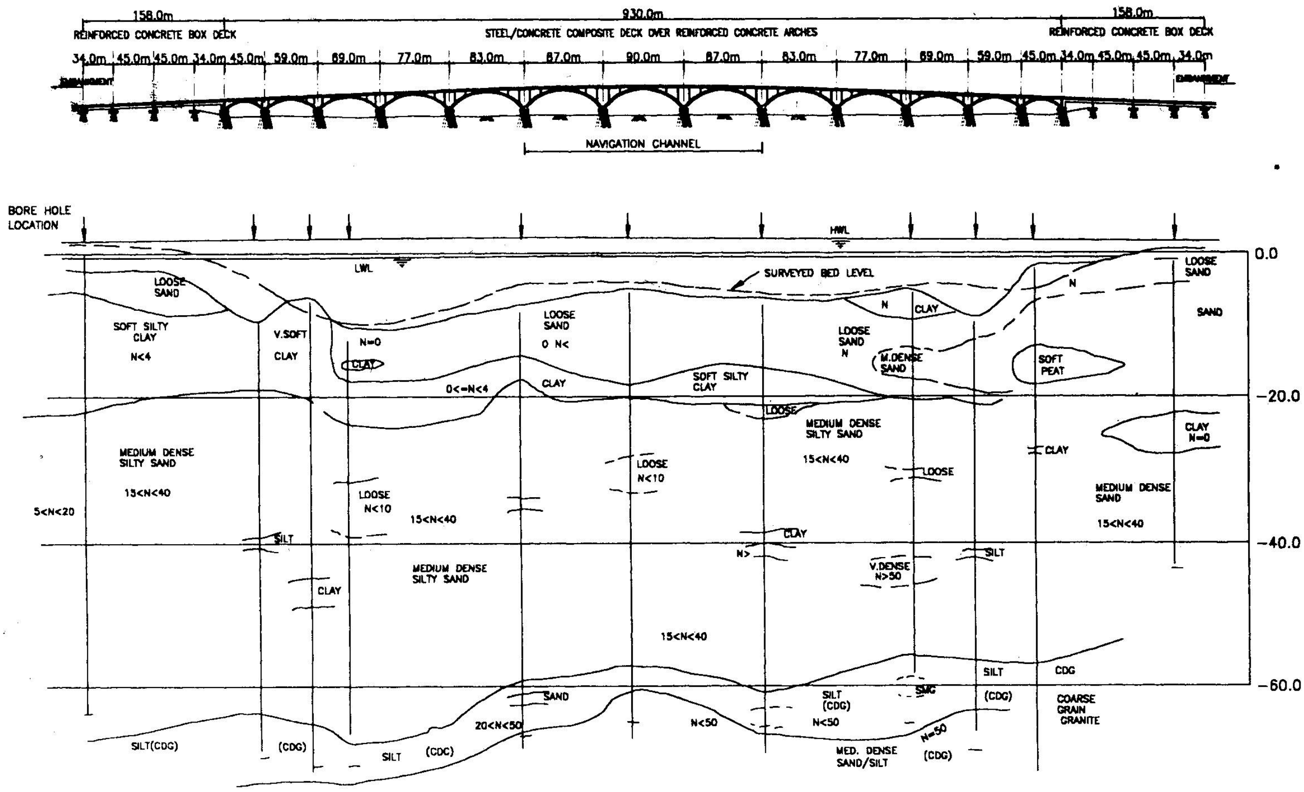


Fig.1 : GENERAL ARRANGEMENT & SOIL PROFILE

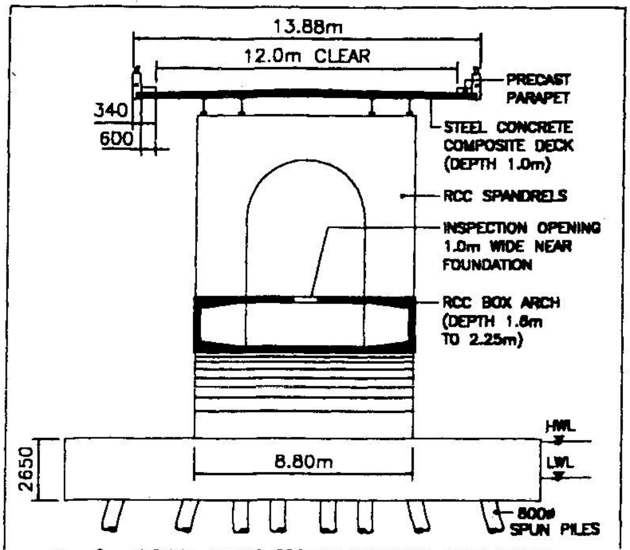


Fig. 2 : TYPICAL CROSS SECTION THROUGH ARCH SPANS

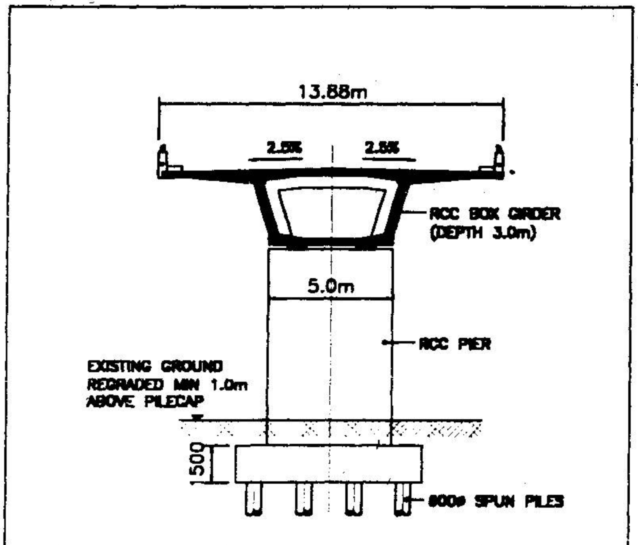


Fig. 3 : TYPICAL CROSS SECTION THROUGH APPROACH SPANS

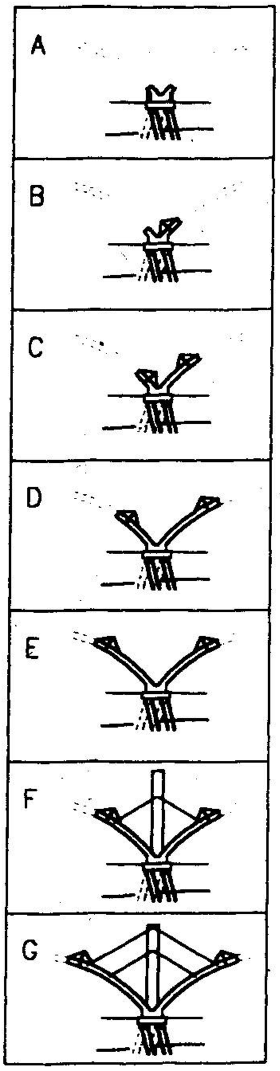


Fig.4 : TYPICAL CANTILEVER CONSTRUCTION SEQUENCE FOR ARCH USING STAY

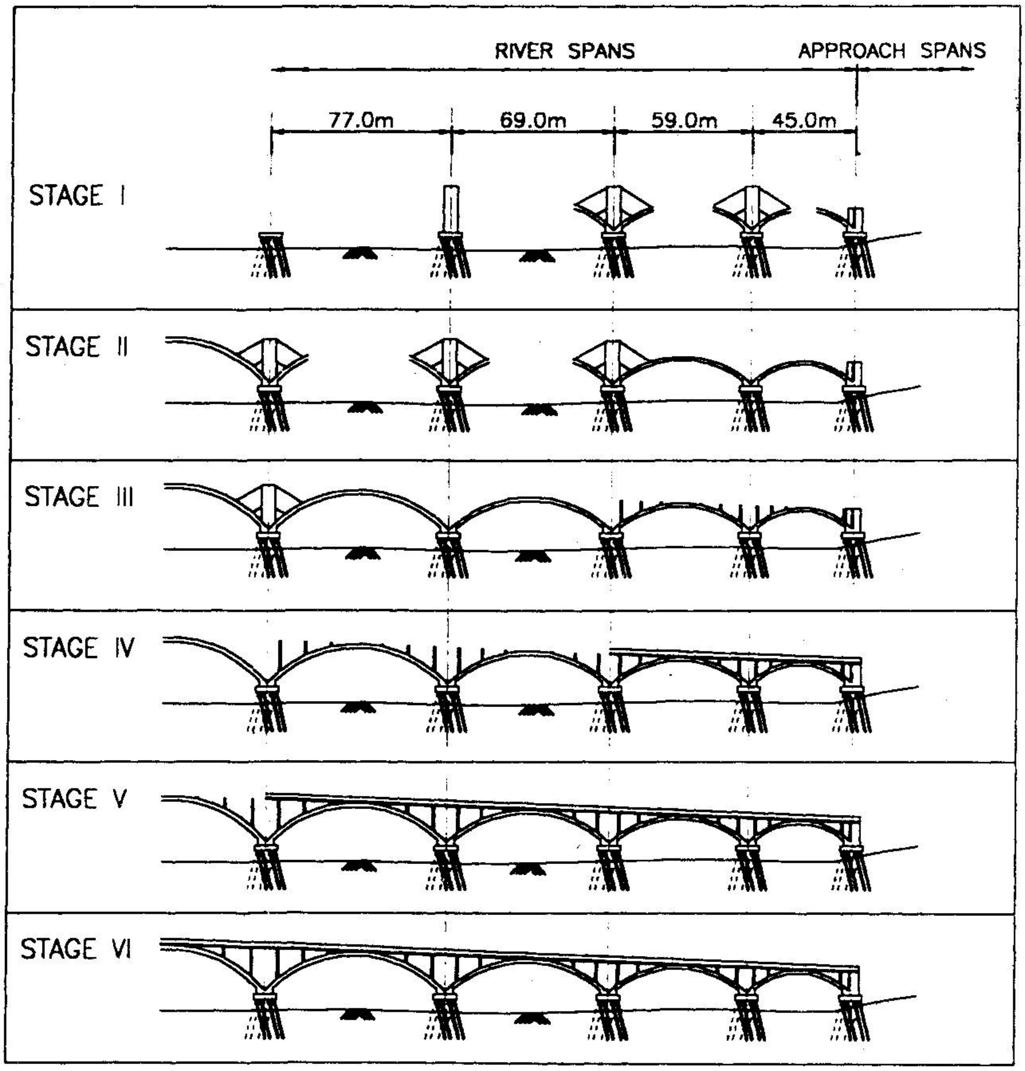
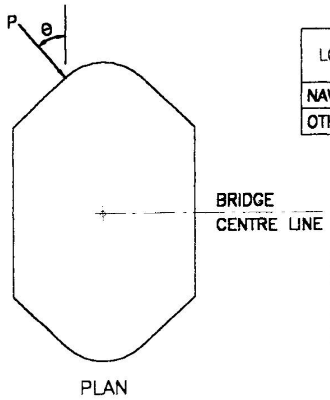


Fig.5 : CONSTRUCTION STAGES FOR BRIDGE



LOCATION OF PIER	ANGLE OF IMPACT, θ						
	0°	15°	30°	45°	60°	75°	90°
NAVIGATION CHANNEL	12	11	10	9.0	8.0	7.0	6.0
OTHER FOUNDATIONS	6.0	5.5	5.0	4.5	4.0	3.5	3.0

VALUES OF STATIC LOAD P (MN)

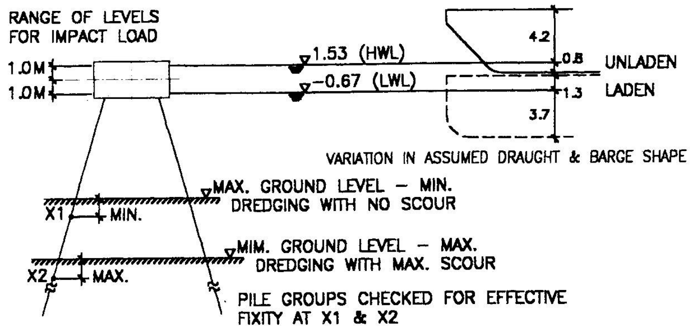
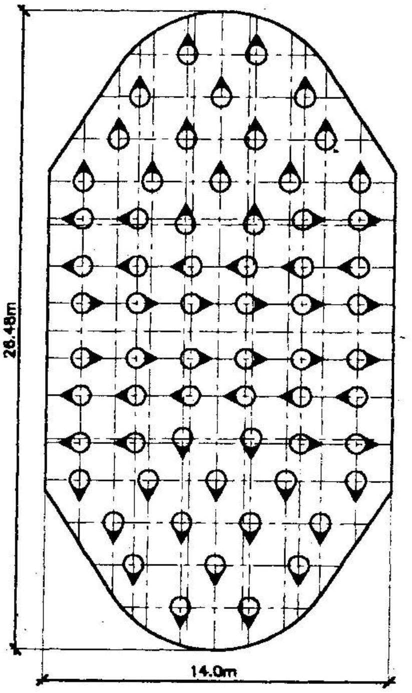


Fig.6 : LOADING ASSUMPTIONS FOR SHIP IMPACT



TOTAL PILES = 84 Nos.
RAKE = 1:4 (DIRECTION SHOWN)

Fig.7 : TYPICAL PILE SETTING LAYOUT FOR NAVIGATION PORTION

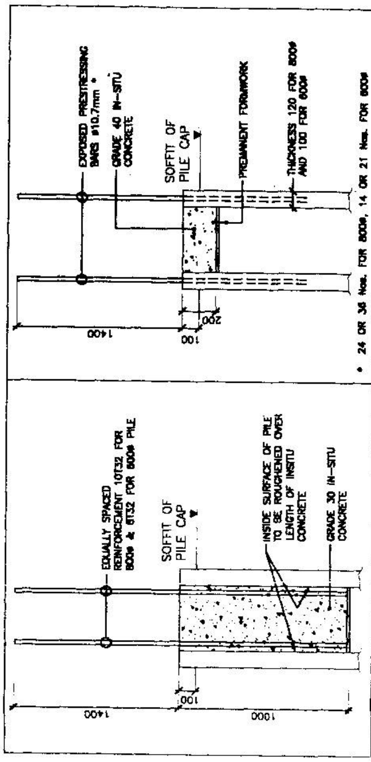


Fig.8 : TYPICAL ALTERNATIVES OF JOINT DETAIL OF PILE WITH PILE CAP

Load factors and load combinations for highway loading shall be in accordance with BS 5400: Part 2 as implemented by BD 37/88. Additional load factors and load combinations shall be as described below :

loading	loadcases 1 – 5 SLS	loadcases 1 – 5 ULS	A ULS	B ULS	C ULS
self wt.	*	*	1.0	1.0	1.0
superimposed DL	*	*	1.0	1.0	1.0
carriageway surfacing	*	*	1.0	1.0	1.0
LL–HA	*	*	0.0	0.0	0.33
LL–HB	*	*	0.0	0.0	0.0
LL–pedestrian	*	*	0.0	0.0	0.0
temperature	*	*	0.0	0.0	0.0
shrinkage	*	*	0.0	0.0	0.0
bearings	*	*	0.0	0.0	0.0
stream flow	1.0	1.5	1.0	1.0	1.0
ship impact	0.0	0.0	1.0	0.0	0.0
progressive collapse	0.0	0.0	0.0	1.0	0.0
seismic	0.0	0.0	0.0	0.0	1.25
river debris	1.0	1.5	0.0	0.0	1.0

* loadcases 1–5 as combinations in Table 1 BD 37/88

loadcase A ship impact
loadcase B progressive collapse
loadcase C seismic

Table 1: LOAD FACTORS & LOAD COMBINATIONS