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Foundation of Bridges on River Ganges in India

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Summary

River Ganges is a very mighty river of India flowing from the snowclad Himalayan Peaks in the North to the Bay of Bengal in the east. Many important civilisations have grown along its banks, resulting in development of many big cities on them. The river bed is rocky to bouldery in the begining and consist of alluvium sand and clay in most of its reach.

The discharge is quite large and flows in many kilometers in width at many places resulting in big meandering tendencies and large concentration of flow. The scour of the bed is also quite substantial which results in very deep foundation. Dozens of Bridges have been constructed over this river which vary in lengths and have different span lengths and different type of structures. But surprisingly, all of them have one type of foundation, i.e. well foundations.

The paper presents the salient features of these bridges with the details of some important requirements of foundations. This will indicate the suitability, feasibility, versatility and economy of well foundations in very challenging conditions. The paper also deliberates on some of the problems faced during sinking and precautions to be taken. Four case studies of different problems faced during construction are also being presented.

Prayer to Goddess Ganges

भगवति तव तीरे नीरमात्राशनो अहं
विगत विषय तृष्णा: कृष्णमाराधयामि।
सकल कलुष भङ्गे स्वर्ग सोपान सङ्गे
तरल तर तरङ्गे -देवि गङ्गे प्रसीद ॥

(" O Goddess ! May I worship my lord Shrikrishna on your sacred banks quenching my thirst only with your water, detaching myself from all wordly temptations. O Goddess ! Thoust who undost all my misdeeds and sins. Thoust who is like an access to Heavens .O Goddess Ganges ! Be Happy on me")

The Ganges - The Sacred River

River Ganges is supposed to be the mightiest and holiest rivers of India. Its origin is at Gomukh/ Gangotri in the snow capped Himalayan ranges in District Uttarkashi at Latitude 30.55' N and longitude 79 7' E and after travelling about 2525 Km. along its winding course through the State of U.P., Bihar and West Bengal it falls into Bayof Bengal near Calcutta. Other mighty rivers like Ramganga, Yamuna and Ghaghra meet this river near Kannauj, Allahabad and Chhapra, downstream of Ballia distt. in UP, respectively. The total catchment of this river is 1015275 Sq. Km.
Before Indian Independence or say even upto 1958 there was no independent road bridge over River Ganga right from its source to its tail end. There were, however, only 7 Road cum Rail Bridges at (1) Balawali (2) Garmukteswar (3) Rajghat (4) Kachchllaghat (5) Kanpur (6) Allahabad-Curzan and Izat Bridge and (7) Malviya Bridge at Varanasi. Since then about 13 Bridges have been constructed over this river in UP and 2 in Bihar and 1 in West Bengal and One bridge is under construction in these states.

Foundations - Well Foundations

The salient features of all these Bridges are given here which will indicate the wide range of discharge, velocities, flow condtions with large meandering tendencies, widths and scour conditions, large variation in depth of flow and sub soil conditions as well. It, then, is a revealing fact that the foundations of all these major Bridges built in very challenging and complex situations are all on well foundations.
The variation in discharge is from 10000 Cumecs to 100000 Cumecs , in depth of water from 6 m to 20 m, in length of Bridges from 641 to 5545m, in the depth of scour from 5 m to 36 m below LWL , in dia of well from 5 m to 13.26 m and in depth of foundation from 17 m to 65 m below LWL sunk in bouldery, sandy, clayey and hard stiff clayey stratas.

This foundation system has shown its versality, feasibility and economy practically for all the condtions of river flow and behaviour, resulting in its wide acceptability and use in India

Name of the Bridge	Discharge (Cumecs)	Depth of Flow(m)	Length of Bridge (m)	Dia of Well(m)	Depth of Well(m) (Scour LWL m)
1. Chandighat, Hardwar	19114	10.0	1257.0	6.00	17(8.35)
2. Garmukteswar	9943	16.0	704.5	9.52	33 x4.88 (Dumb shaped well)
3. Farrukhabad	15625	15.0	641.7	5.5	26.9
4. Kannauj	20000	6.0	820.0	5.5	32.21
5. Jajmau,Kanpur	22470	8.0	713.0	5.5	38.35 (22.4)
6. Nanamau	20500	7.0	740.5	5.25	40(26)
7. Gigason, Raebarei			1036.4	5.5	30
8. Phaphamau Allahabad.	27000	11.0	963.4	5.5	29
9. Shastri Bridge Allahabad.	26350	11.0	2083.0	5.5	30
10. Ram Nagar Varanasi	46180	15.1	920.5	13.0	65
11. Mirzapur	42475	-	1001.0	5.5	33
12. Gazipur	50970	12.5	1022.0	8.5	43.5
13. Bhagalpur	94000	11.5	4367.0	11.66	64.70(36)
14. Patna	99600	9.5	5575.0	13.26	55.65

(Photos P1 to P6)

Some Problems faced in the construction of well foundations

These problems may be because of -

1. Short term effects - tilts, shifts and cracking etc. during sinking.
2. Long terms effects - Scouring, non uniform strata, constant overloading, eccentric loading and deterioration etc.

The problems as such arise during construction itself or during service period.
The problems are mainly because of the following factors -

(a) Hydraulic -

(i) Incorrect assesment of design discharge and highest flood level.
(ii) Wrong assesessment of the concentration of flow near the foundations and ignoring its effect.

(iii) Wrong assessment of the scour because of the use of a wrong formula without knowing its limitations.

(iv) Wrong or inadequate assessment of sub soil parameters which also result in wrong assessment of scour.

(v) Incorrect assessment of the velocity of the river or tidal or wave effects.
(vi) Incorrect assessment of the buoyancy forces in case of floating cassion etc.

(b) Geotechnical

Lot of problems, which may arise because of improper and inadequate Sub Soil & Geotechnical investigations, may be because of. -

1. Selecting unsuitable type of foundation.
2. Selecting a weak or improper strata for resting the foundations.
3. Assuming wrong values of soil parameters, which may result in selecting faulty or ineffective technique for construction.
4. Fault or adverse dip in case of rock foundation.
5. Non uniform soil strata at the base or in the grip zone.
6. Artesion Conditions.
7. Seismic effect.
8. Wrong assessment of the soil foundation interaction.
9. Improper methods and techniques of construction.

These create problems of excessive tilting or stucking of well during construction, or excessive tilting or settlement during service . In many cases well foundations tilt because of being seated over a non - uniform strata, part being on rock and part being on soil, or the well resting on slopy strata or uneven strata. Poor or weak strata at the base or poor soil properties in grip zone as compared to those considered in the design, may result in excessive settlement.

The remedy to all such problems is possible only if the tilt and shift and settlement are within permissible limits and have resulted in controllable settlements.

The artesian condition may also result in non workable and unstable conditions and needs to be controlled immediately. This may cause sudden and uncontrolled sinking by own weight of the well and result in excessive sinking, cracking or tilting etc.

Preventive and Remedial Measures.

The problems can be dealt with proper preventive measures or methods and techniques during the construction stage and by proper rehabiliation scheme in service stage.
Some of the measures usually adopted are as follows-

1. In case of sinking in the boulders, stronger cutting edge with an inclined inner plate

and better grade of concrete in well curb be used . The boulders may have to be carefully blasted to remove big boulders and to shake the well.

2. Grabing operations should be regulated so that the presence of big boulders may not obstruct sinking in some part and result in slipping, tilting or shifting of well. In such case excess grabing should be done on higher side. Sometime Divers have to be sent to take out the boulders under the cutting edge.

3. Where the grabing operations are not successful in hard strata, dewatering is done to make open excavation possible.

4. Where dewatering is not possible external loading is done bysome suitable load. Such type of loading is also resorted to where the well is stuck up in some strata . In such cases, loading is further supplemented by water jetting or air jetting etc. also.
5. Use of strutting techniques , may be with use of sal- ballis, can be made to check tilt of the well.
6. Pulling the well withropes etc is also done to correct the tilt.
7. Eccentric loading on the well is also done to rectify the tilt.
8. In case the steining cracks because of some problems in the sinking, which may permit water to seep through and at lower depths shoot out under some pressure, it causes difficulty in doing the repair work. These cracks have to be sealed with neat cement at far as possible. Wider cracks should be plugged with pieces of gunny bags soaked in cement mortar. At still lower levels a method is devised to collect the water and allow it to be discharged inside the well without fouling the space where concrete is to be placed.
The cracked steining is strengthened by laying another RCC steining inside the cracked well, in contact with the old steining.
9. The artesian conditions met during sinking of well of foundation are to be controlled and stabilised by creating a head of water inside after constructing false steining etc.

Case Studies

1. Sinking of a Well foundation.
in a depth of 64.70m below LWL for a 4.4 Km. long Ganges Bridge

The 11.6 m dia single circular well foundation was to be sunk to a depth of 64.70 m below LWL. The discharge of the River Ganges at the site being 94000 cumeces, the calculated maximum scour depth being 36 m below LWL, the water depth at HFL being 23 m above bed velocity being 4.5 m/see. The foundation well was started to be sunk when the water depth was about 12 to 13 m.

The soil strata in general was sandy in the upper layers upto 25-30 m below bed followed by very hard and stiff clay layer, sometimes mixed with kankar. However , in the above location, there was hard clay all through with a intervening layer of hard stone in about 2 m depth. The work of this foundation was started in the month of March by making a 13 m heigh sheet pile Island filled with sand . The curb was cast at the top of this island and sunk through this filled up sand. After the well reached the bed of the river it met with hard and stiff clay strata mixed with kankar. The river bed was sloppy towards one side which resulted in tilting of the well. The well had to be loaded eccentrically against the direction of tilt with about 180 T load. The well was also tied by means of wire ropes with the next well which had already been completed earlier and bottom plugged. The sinking was done by chiselling and grabbing. The weight of the chiesel used for this was 2.5 T.

The rate of sinking achieved in this layer was about 1.98 Cm/hr.

The clayey layer was followed by rocky strata at about 18 m below the bed. The well was loaded by concrete blocks of about 180 T and sinking was done by chiselling and grabing operation.

The rate of sinking achieved in this layer was about 1.41 Cm/hr.
The hard and stiff clay layer which followed after this was dealt with by chiselling and grabing as above but under loaded conditions with 250 T concrete block over the well. The dewatering of the well was also done to make sump of the required depth to facilitate sinking. The rate of sinking in this third layer was 1.64 cm/ hr. The well was finally sunk to its foudning level about 65 m . below LWL in the sandy strata . The total crane hours for sinking were 3500 hrs.

(Photos 1 to 4 and Sketch - 1)

2- Revival of Submerged Curb

The location of this foundation was in the mid - stream of river Ganges. The diameter of well was 11.66 m with steining thickness as 3.1 m and curb was of height 5.54 m. The curb was proposed to be cast in two lifts of 3.12 m and 2.42 m respectivelty . Here also, the sheet pile island of 16 m dia was constructed at the location of well in a water depth of about 10m, for laying the well curb at its top. The concreting of first lift involving 180m3 of concrete was done in 2 days.
After about One and half hour of the concreting, leakage of sand from the island occured in the upstream side. As a result , the entire curb, after getting tilled towards upstream side, sunk nearly 4.50 m below the water level.
The tilt was corrected by performing the grabbing in between the curb and sheet pile island in the down stream side. After correcting the tilt as above under water, and making the curb vertical, another sheet pile island was made inside the earlier island at a gap of 0.75m. This gap was filled with clay and bags filled with clay. After filling the gap, the dewatering of island was done by means of 4 submersible pumps of 20 KW capacity to a level lower than the concrete level of curb. The shuttering was then erected and reinforcement fixed and immediately concreting of further steining was done. This operation of dewatering and

concreting was continued for nearly 24 hours to complete the concreting of second lift, which also brought the curb top above the water level. The whole process took one complete month. Details shown in the sketch - 2

3. Revival of Over Sunk Well

Some times , the well sink suddenly because of excessive grabing or sump or some weak soil layer and the steining of well , done upto that stage which is always kept above the water level by regulating the sinking and concreting operations , goes below the water level making it difficult to continue further work on steining.

In this case , a well foundation was being sunk in deep waters of River Ganges. The total height of steining except last 2.00 m was completed and the well was left to be sunk finally by about 7.5 m to reach its founding level. As the strata was of stiff clay in which the well was stuck up , chiselling and grabing operations were continued to make a sump of about 8 m below the cutting edge. This position of well remained for quite some time. Then one day the well sunk suddenly by 8.91 m, 1.43 m extra below the final founding level. Due to this extra sinking the top of steining also went below the water level by about 3.50 m. All this happened just before the monsoons when the water level started rising and work could not be continued. After the flood receded and water levels normalised, the work was resumed . It was found that the depthof water was 2.5 m. The well was in side the river bed and about 25m from bank. Sand embankment was made from the bank to extend and cover up the location of the well. A cutting edge of 2 m more dia than the dia of well was placed there and a cofferdam with 30 Cm steining thickness was made and got sunk to nearly 0.50 m below the top of the steining of the over sunk well. The concrete cofferdam was then dewatered and steining of the original well was exposed making it feasible to build up further steining to the required level. Details shown in sketch- 3.

4 - Scouring of Foundations during Construction Stage - Programme for Reconstruction

Two well foundations of a Bridge under construction over River Ganges were scoured below the cutting edge level during the floods and were carried with the flow and laid almost horizontally. The location of the well could not be traced as it was buried inside the scoured bed , later on silted A number of methods were tried to locate the top of these well. When wells could neither be seen by naked eye nor could be located by various methods , i.e., weight dropping method. Echo sounding method and through divers after the water level receded,expioratory borings had to be done to trace out the position of the well foundations. This is shown in the sketch.

From the perusal of the data it was seen that at the time of floods these two wells were already sunk to a safer level as far as the normal design scour was concerned and the other wells sunk to this level the same time and in previous years stood well during the floods. However, the design HFL was also not achieved (was about 1.5 m less) which left no further margin of safety in the depth of foundation at that time. The detailed [illegible] conditions revealed that there was probably an unprecedented [illegible] of the Bridge which resulted in excessive scour [illegible] wells

Proposal for Reconstruction.

As the scoured wells were still obstructing the old foundation locations, the span arrangement had to be changed and two proposal were considered for laying the new well foundations.

Alternative-1

By laying the new well foundation on island to be constructed with steel sheet piles.

Alternative - 2

By floating Steel Caission and Gantry Arrangement

Because of thechange in flow conditions and excessive scouring in this zone, the depth of water was in the range of 17m to 22 m. For such deep depth of water alternative I which was the construction Technique adpoted for other wells, was not feasible.

As such alternative II is to be used. This is the arrangement of fabricating steel curb and steining segment, lifting in vertical direction, shifting and placing the same on the barge and taking it to the location of the well foundation, lifting with steel gantry arrangements on the gantry barge, removing the caisson barge, lowering the steel caissons segment with the gantry arrangement and concreting of the same in such a way that it remains floating all the time due to its bouyancy effect till it touches the bed level of the river at the foundation location, sinking a little bit more as considered safe for laying another segment of steel caisson over it so that the bottom of steel caisson rests in the normal bed of the river and top of the last steel caisson segment remains above the water level such that the balanced steining of the caisson could be done directly by fixing shuttering.

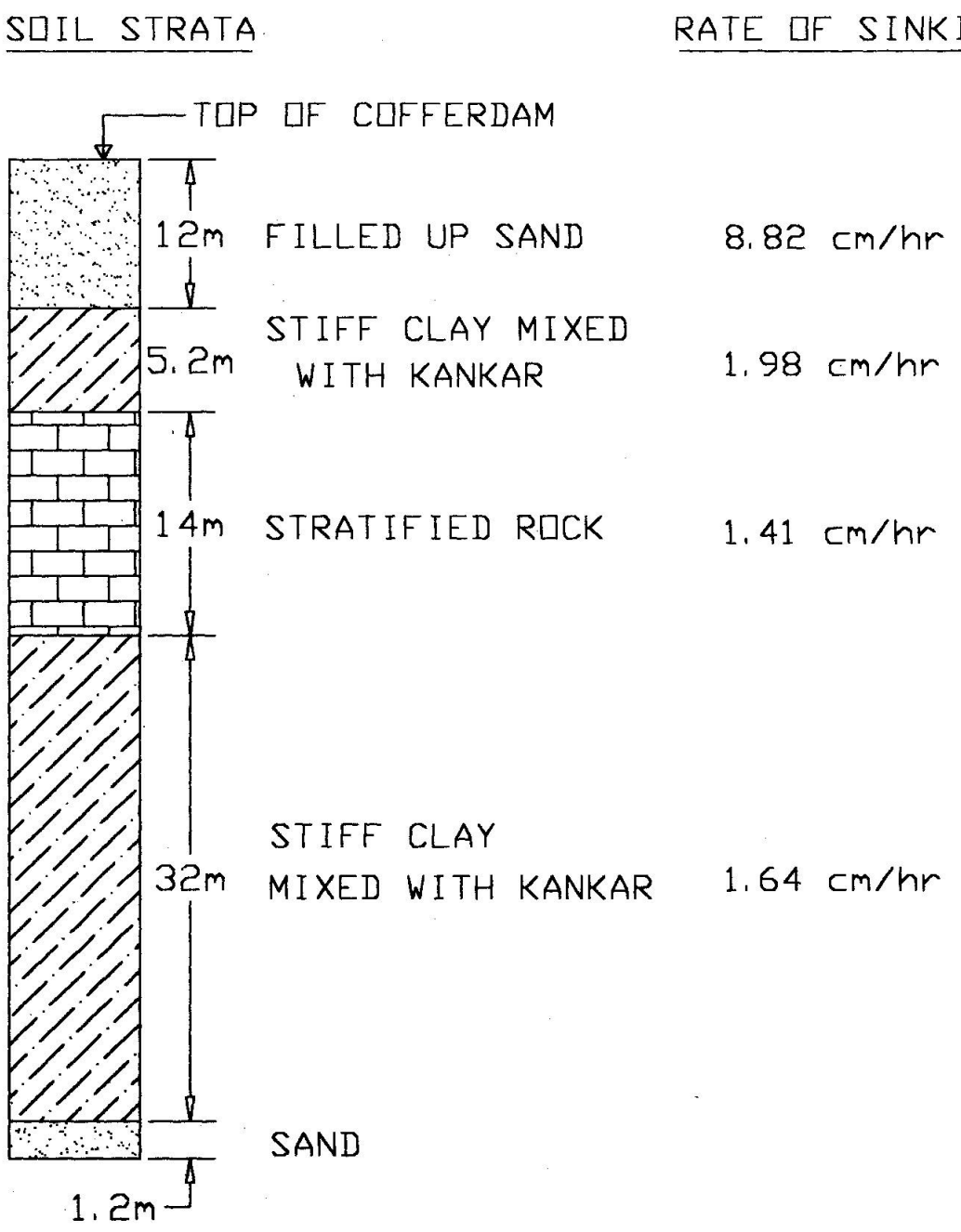
(Sketch 4 to 5)

The above method has already been tried elsewhere and has been quite effective and useful.

Conclusions

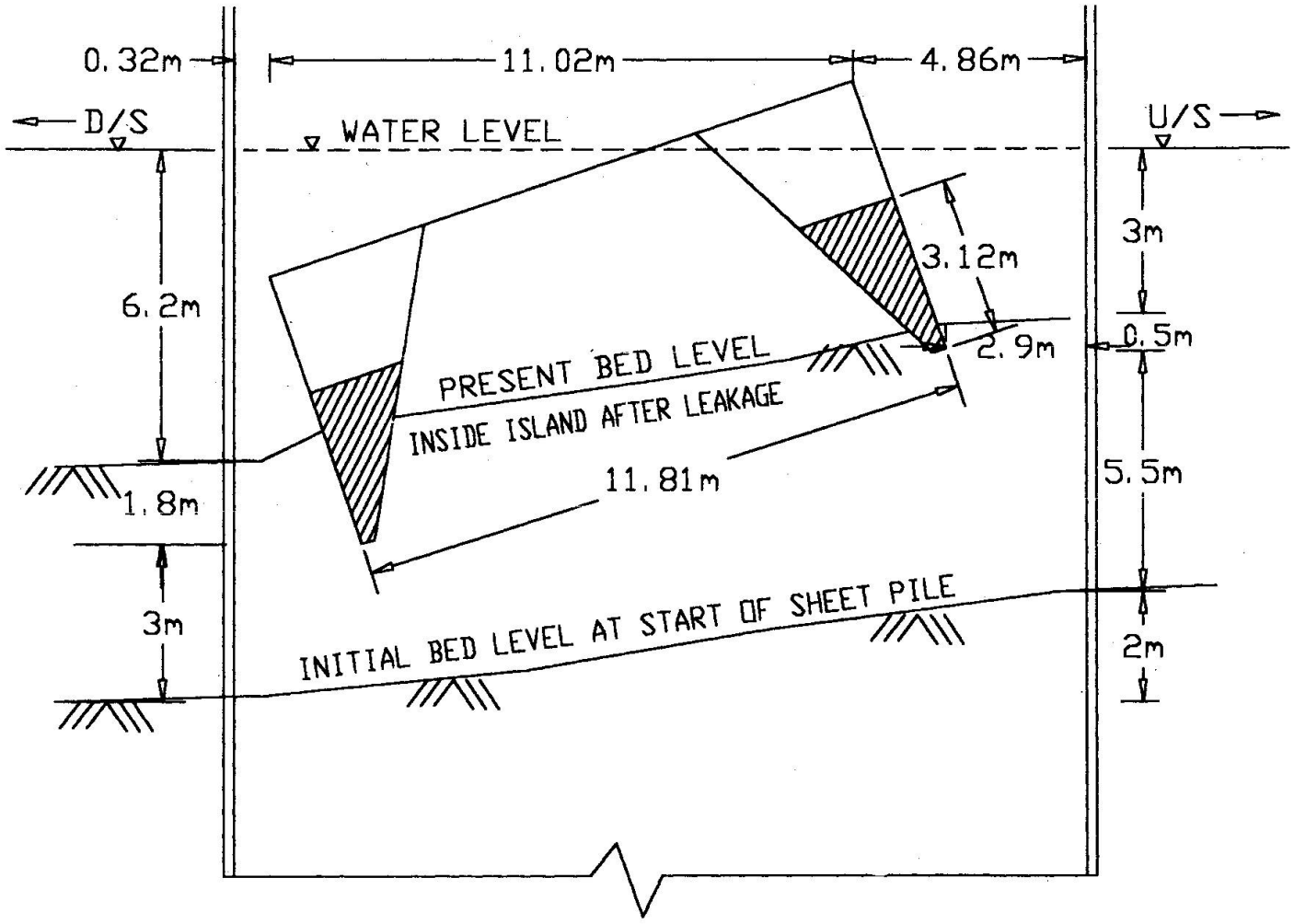
Use of well foundation for so many Major Bridges on such mighty river in different conditions indicate that these type of foundations are the best solution for the scouring rivers.

The case histories as presented above have however, been discussed here to bring out a word of caution to the design Engineers to have proper and adequate hydraulic and Geotechnical Studies and investigations done and to construction Engineer working in the bed of such mighty rivers having very large depths of water and discharge, to remain alert to the flow condition of river and scouring pattern so as to take timely preventive measure to check such happenings which take lot of time, effort and money in ractification.



CASE STUDY 1 - DETAILS OF STRATA & RATE OF SINKING

SKETCH 1



CASE STUDY 2 - REVIVAL OF SUBMERGED CURB

SKETCH 2

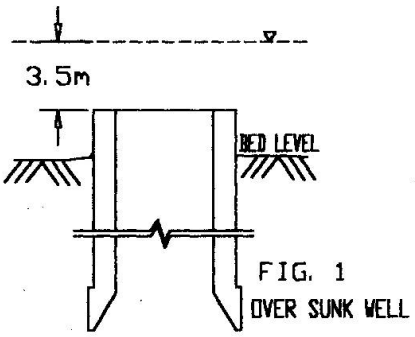


FIG. 1
OVER SUNK WELL

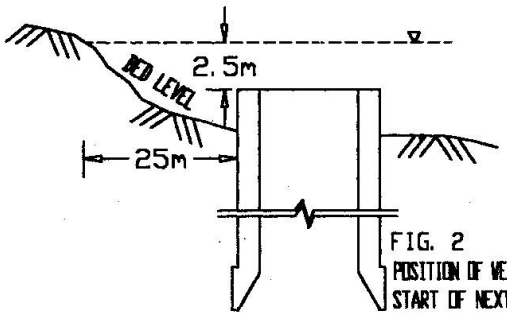


FIG. 2
POSITION OF WELL AT
START OF NEXT SEASON

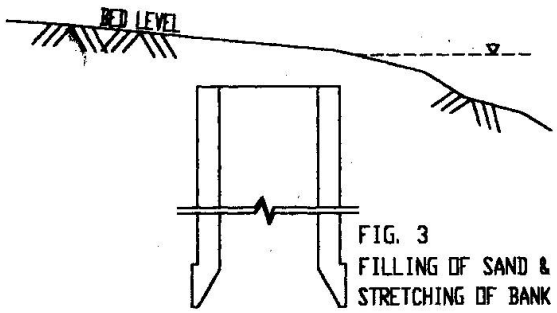


FIG. 3
FILLING OF SAND &
STRETCHING OF BANK

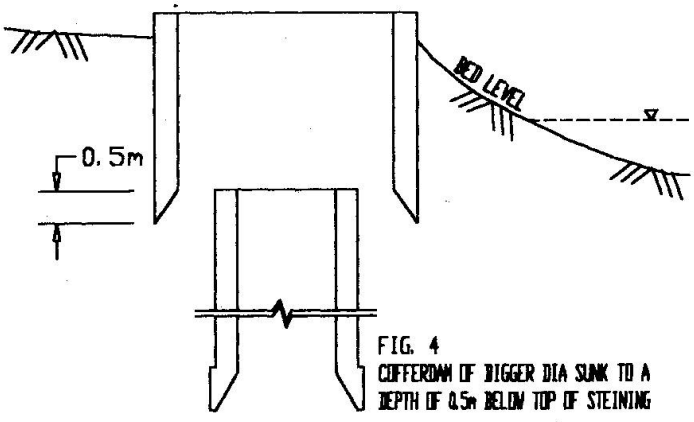
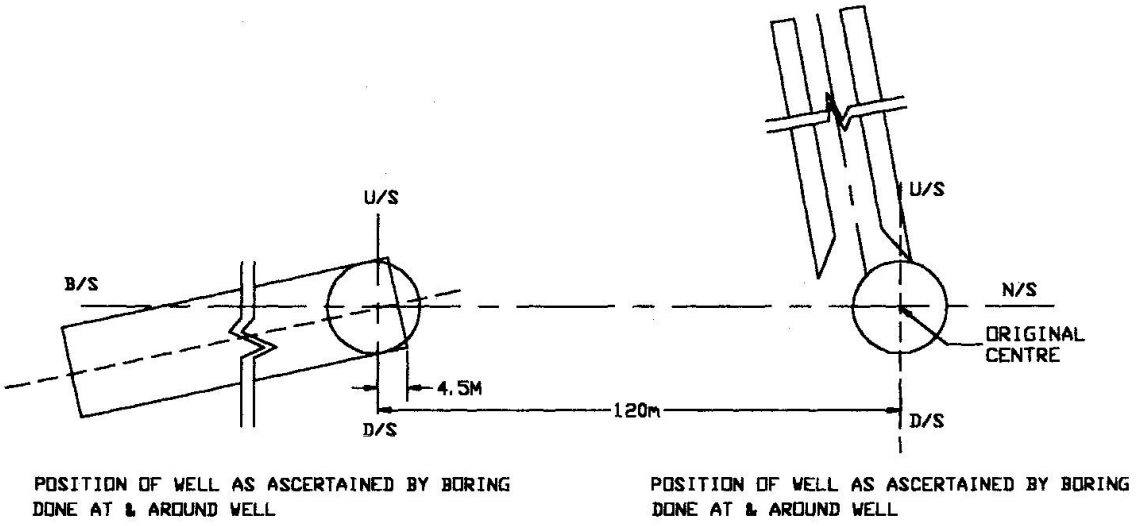


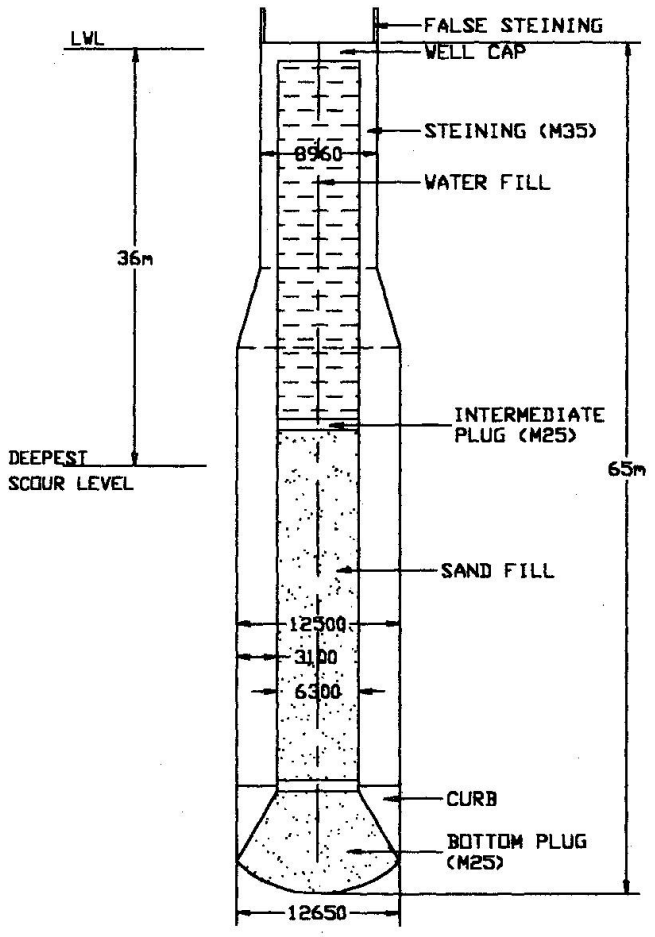
FIG. 4
COFFERDAM OF BIGGER DIA SUNK TO A
DEPTH OF 0.5m BELOW TOP OF STEINING

CASE STUDY 3 - REVIVAL OF OVERSUNK WELL

SKETCH 3

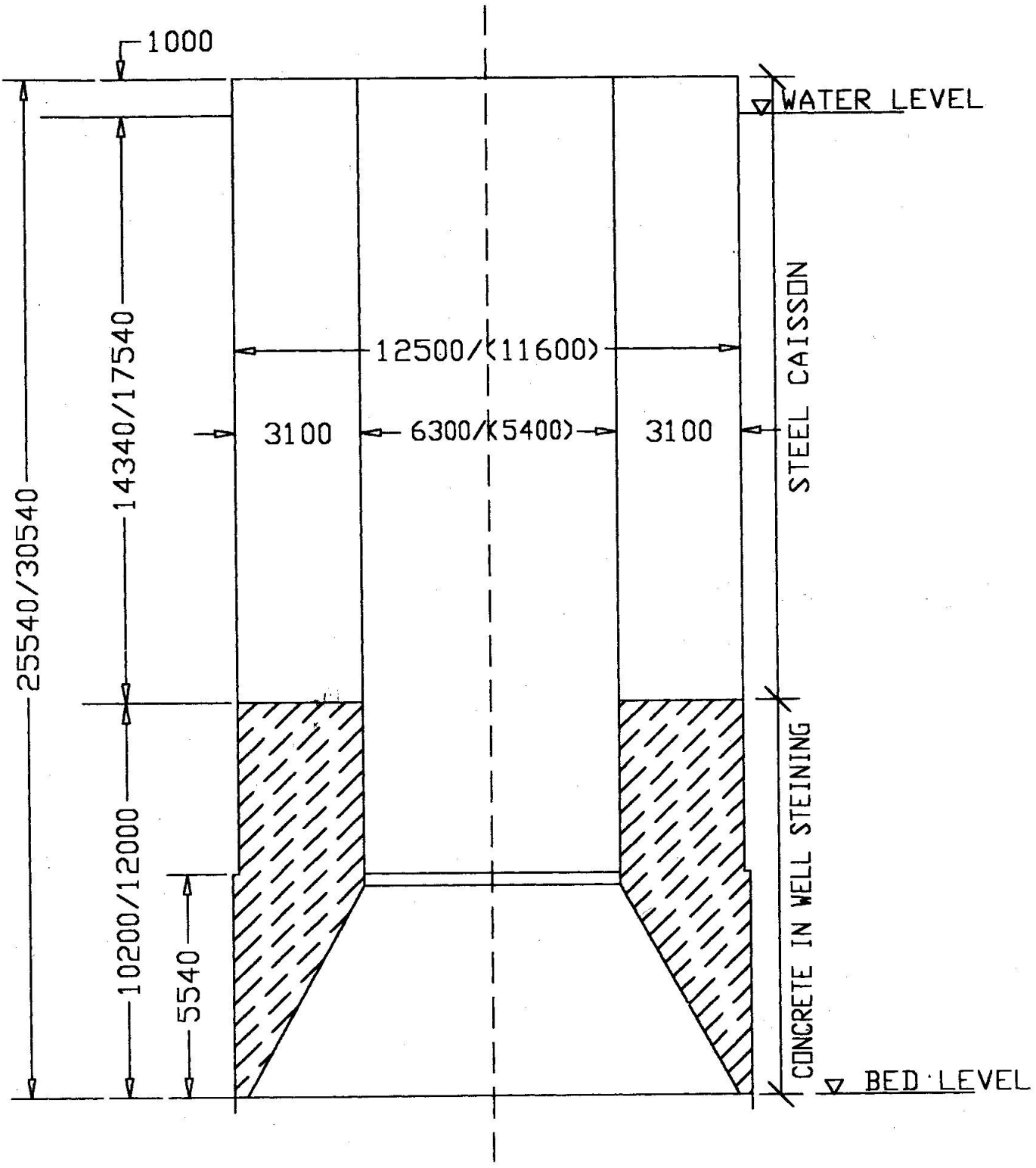


CASE STUDY 4 - SCOURING OF FOUNDATIONS DURING CONSTRUCTION



CASE STUDY 4 - TYPICAL CROSS SECTION OF PIER WELL

SKETCH 4



CASE STUDY 4 - LAST STAGE DURING GROUNDING OF CAISSON

SKETCH 5