



“Retrofitting Of Well Foundation” - Design to carry Heavy Axle load trains & PSC beams.

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Synopsis:

Well foundations are stronger & durable foundations having enormous reserve strength and can carry heavy PSC girders and 25t axle load, by adopting appropriate retrofitting techniques. In many of the bridges existing well foundation also gets exposed due to large amount of scour/sand mining problems. In this paper, these well foundations are proposed to be strengthened by using RCC ring/grade beam surrounding the well (primary foundations) at the scoured Bed level which are further supported by Under Reamed Piles (U/R-piles) of required size at suitable centers below the ring/grade beam (secondary foundations). This makes the foundation with the supporting framed structure monolithic & sturdy enough to carry the increased vertical & tractive forces. The proposed mode of strengthening of well foundation by additional primary & secondary foundations is termed as “Retrofitting Of Well foundation” in this paper.

1. Well Foundations – An efficient structure:

Well Foundations are strong and sturdy foundations suitable for carrying heavy axle loads, Stable against sliding & overturning etc., and are efficient structures adopted in any type of soil strata.

Due to heavy mass buried below bed level, C.G is lowered & well gets anchored. It is more suitable to carry ground motions &

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earthquake loads and has enormous reserve capacity/strength in all directions since anchored adequately into the ground.

Retrofitting of Well Foundations - The Need:

Well foundations are more opt where soil strata comprise of sand or stiff clay. Size and shape of well depends on the size of pier, feasibility of dredging....etc., Weight/m² of peripheral surface is higher, which facilitates sinking of well. Load transfer is mostly by end bearing and SBC of soil determines the size of well.

Well foundations often gets exposed at many locations due to large amount of scour / sand mining problems such as at Br.No.482, Br.No.167; kuzhithurai river Br.161,... etc., in Southern Railway. The existing well foundations are proposed for strengthening using RCC Ring / Grade Beam surrounding the well and upto the scoured Bed level, supported by under reamed piles of required capacity at suitable centers below the ring grade beam. The piles are taken atleast upto the bottom level of the well foundation to obtain / develop adequate bearing / frictional forces.

Most of the well foundations in IR are more than 100 years old and continue to carry the steel girders and super imposed axle loads without any distress.

When it becomes necessary to replace steel girders into PSC/RCC girders and also when higher axle load trains are proposed to be run, the well foundations have to be retrofitted adequately by providing additional arms to well (see the sketch enclosed).

1. The load transfer mechanism:

The annular RC capping slab (Ring beam) acts as a spread footing and carries/transmits part of the super imposed loads. The jacketed pier distributes the load over large bearing area and hence the intensity of loading gets reduced. Self weight of pier is assumed to be carried by well structure itself.

As per IS 2911 para 5.2.7.2, spacing of U/R piles is $< 1.5D_u$ and



>3m .Hand augured cylindrical piles (without under reaming) can also be used in the case of non clayed soil. Due to large annular bearing area at the base of the eroded bed level, stability of the well gets enhanced.IS-2911 provide ready table for calculating the carrying capacity of small diameter U/R piles for various diameter & bulbs.

The increase of load intensity (18.3m Steel girder if replaced into PSC 'U' girder):

- Vertical load due to 'U' type PSC girder for 18.3m of span is of the order of 145 t (compared to approx. 26t due to steel girder) } =500% increase
- The lateral forces due to Earthquake oscillation get increased by } =150%
- LL for double span condition = 81.4 t.
- Total vertical load = 447t.
- Longitudinal / tractive force =2x14.99t on the well
- Water pressure = 4.5t .
- Total lateral force = 34.57t.

3. When strengthened by piles all round during ground motion:

Vertical hold-down improves when strengthened by piles and hence response during ground motion. Soil- structure interaction also gets enhanced. Capacity design is achieved by inhabiting undesirable in elastic deformation during earthquake. Piles may be either of under reamed type or shorter & smaller diameter bored cast-in-situ piles

- **Self compacting concrete (SCC) can be advantageously used for these hand bored piles:**

SCC when mixed with admixtures give early strength & exhibit



better characteristics and denser concrete. 53 grade OPC with SCM (supplemental cementations material) as partial replacement produces highly durable concrete up to 80 Mpa.

- **SCC for Under reamed piles of Single / Double bulb:**

Testes conducted at SERC / Chennai has proved that Dynamic characteristics such as natural frequencies, %damping, resonant acceleration response, and normalized resonant displacement response are superior when SCC is used. Silica fume in combination with either fly ash or GGBS could also be used to ensure early development of strength in wet soil conditions (river water/ ground water). High density of concrete can be achieved by filler material such as denzified silica fume and by acceleration of cement hydration.

- 4. **Precautions during piling & concreting:**

Piling equipments shall not infringe the safety & stability of the existing structures. Boreholes drilled for bored casting piles shall be flushed before placing of reinforcement cage for concreting. Admixtures may also be used and buildup of concrete controlled.

High speed & high train operations – Need to replace steel channel sleepers

- 5. **High speed & higher axle loads:**

As per RDSO's report CT-20 Rev-2 (para 2.4.4) issued in November 2009 existing wooden and steel channel sleepers are fit to carry trains only upto 100kmph. At higher speeds resonance condition may occur leading to heavy oscillations and running will become rough. Hence it is advisable to have uniform track structure with 60kg PSC sleepers over the PSC span of 18.3m major / important bridges. Thus steel girders need to be replaced into heavy weight PSC spans ('U' type or PSC box) which can be arranged at optimal cost by retrofitting of well foundations described herein.



6. DESIGN FOR STRENGTHENING OF EXG. OLD WELL FOUNDATION WITH RING BEAM AND UNDER REAMED PILES: (Other piers):

500Ø Double Under Reamed Piles (P8 & P11- Shallow wells):			
-	Depth below Scoured Bed level	=	9.58m.
Piles upto the bottom of well foundation.			
-	No. of Piles	=	8 No.s
-	Well Diameter	=	3.66m
-	Ring beam / girder at scoured bed level		1500 x 800 thick (4/16 Ø reinf. at top 4/125 Ø reinf. at bottom 10Ø reinf. 4 legged stirrups at 150cm.)
-	Piles	=	12 / 12 Ø Reinf. Rods. (8 Ø reinf. Rings @ 300cm.)
-	Capacity of 8 no.s of 500 Ø Double under reamed piles	=	796 t > 447 t
-	Capacity of 8 no.s of 500 Ø piles in horizontal direction	=	43.20 t >34.57 t

For pier no. P8:			
-	Depth below Bed level	=	7' + 31' + 4' = 44' = 13.41m
-	Depth below Scoured Bed level	=	13.41 – 3.83 = 9.58m
-	Diameter of well	=	4.250m
As per table 1 of IS 2911-3			
-	Diameter of pile d	=	30cm
-	Underreamed of Pile=2.5d	=	75 cm



-	Length of Double Under reamed Pile	=	3.5m
-	Compression load for Double under reamed pile	=	24 t (from IS 2911, table .1)
-	Increase per 30cm length	=	1.40 t
-	Length of grip (depth) $9.58 - 3.5$	=	6.08 m
-	Multiples of 30cm $6.08 / 0.30$ (hence extra capacity.	=	$20.27 \times 1.40 = 28.378$ t
-	Capacity of each pile	=	$24 + 28.378 = 52.378$ t

-	Spacing	=	$2.0 \times 0.75 = 1.50$ m Clause 5.2.7 of IS:2911 (Part III)
-	Circumference of well along pile centre	=	21m
-	No. of under reamed pile	=	$21 / 1.50 = 14$ say 16 no.s
-	Capacity	=	$16 \times 52.378 = 838$ t > 447 t
-	Lateral thrust capacity for double under	=	2.4 t
-	For 16 No's, total lateral capacity.	=	$16 \times 2.4 = 38.4$ t > 34.5 t (i.e., longitudinal force)

Design of circular Grade Beam: (Double 'D' shaped grade beam)

	Dia. of grade beam	=	5.00m.
	Moment coefficients in circular grade beam:		
-	Load /m run: (DL = 142 t + LL = 81.65 t = 223.6 t)	=	$223653 / (n \times 5.00) = 14245$ Kg/m
-	With piles as columns (-ve B.M @ support)	=	0.0342 w. l
-	With piles as columns (+ve B.M @ support)	=	0.0176 w. l
	Span $l = 50 / 2$	=	2.5 m.



IS 2911 – Part III – 1980

TABLE 1 SAFE LOAD FOR VERTICAL BORED CAST *IN SITU* UNDER-REAMED PILES IN SANDY AND CLAYEY SOILS INCLUDING BLACK COTTON SOILS

SIZE		LENGTH		MILD STEEL REINFORCEMENT			COMPRESSION				SAFE LOADS IN UPLIFT RESISTANCE				LATERAL THRUST	
Dia- meter of pile	Under reamed dia- meter	Single under- reamed	Double under- reamed	Longitudinal Reinforcement	Rings spacing of 6mm dia rings		Single under- reamed	Double under- reamed	In- crease per 30 cm Length	De- crease per 30 cm Length	Single under- reamed	Double under- reamed	In- crease per 30 cm length	De- crease per 30 cm length	Single under- reamed	Double under- reamed
cm	cm	m	m	No.	Dia mm	cm	t	t	t	t	t	t	t	t	t	t
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
20	50	3.5	3.5	3	10	18	8	12	0.9	0.7	4	6	0.65	0.55	1.0	1.2
25	62.5	3.5	3.5	4	10	22	12	18	1.15	0.9	6	9	0.85	0.70	1.5	1.8
30	75	3.5	3.5	4	12	25	16	24	1.4	1.1	8	12	1.05	0.85	2.0	2.4
37.5	94	3.5	3.75	5	12	30	24	36	1.8	1.4	12	18	1.35	1.10	3.0	3.6
40	100	3.5	4.0	6	12	30	23	42	1.9	1.5	14	21	1.45	1.15	3.4	4.0
45	112.5	3.5	4.5	7	12	30	35	52.5	2.15	1.7	17.5	25.75	1.60	1.30	4.0	4.8
50	125	3.5	5.0	9	12	30	42	63	2.4	1.9	21	31.5	1.80	1.45	4.5	5.4

7. STRENGTHENING OF EXG. OLD WELL FOUNDATION WITH RING BEAM AND UNDER REAMED PILES: (Other piers):

Design of circular Grade Beam: (Double 'D' shaped grade beam)			
-	Max. Twisting Moment	=	0.0053 w.l
-	Max. -ve moment @ support	=	$0.0342 \times 223653 \times 2.5$ = 19122 Kg m
-	Max. +ve moment @ centre of span	=	$0.0176 \times 223653 \times 2.5$ = 9841 Kg m
-	Max. torsional moment @ 15°12' from either support (T).	=	$0.0053 \times 223623 \times 2.5$ = 2963 Kg m
-	Shear Force @ support section v	=	$(14245 \times 2.5 \times (n/4)) / 2$ = 27957 Kg
Design of support section: (600 x 1000)			
-	Effective 'd'	=	$600 - 75 - 12.5 = 512.5$
-	Equivalent Shear Force 'Ve'	=	$V + (1.6T)/b$
-		=	$27957 + \frac{(1.6)(2963)(100)}{100}$
		=	32698 Kg



Design of support section: (600 x1000)

-	Equivalent nominal shear stress Z_{ve}	=	$32698 / (50 \times 71.25)$ $= 9.18 \text{ Kg/cm}^2 < 19 \text{ Kg/cm}^2$ (for M 25 grade concrete)
Longitudinal Reinforcement:			
-	Equivalent Bending Moment M_{e1}	=	$M + M_t$
-	M	=	B.M @ cross section
-	M_t	=	$T (1 + D/b) / 1.7$
-	Where 'T' is the Torsional moment, 'D' is the overall depth and 'b' is the Breadth of beam		
-	M_t	=	$296300 (1 + 80/50) / 1.7 = 453165 \text{ Kg.cm}$
-	M_{e1}	=	$453165 + 1912200 = 2365365 \text{ Kg.cm}$
-	A_{ϕ_t}	=	$2365365 / (2000 \times 0.894 \times 51.25) = 25.81 \text{ cm}^2$

Longitudinal Reinforcement:

-	Provide 4/25 ϕ rods (25.81 cm^2)		
-	$100 \times A_{st} / bd$	=	$(100 \times 19.625) / (50 \times 51.25) = 0.551$
-	Z_c	=	3.26 Kg/cm^2
-	Distance between the centres of corner bars parallel to the width	=	$50 - 2(5 + 1.25) = 37.5 \text{ cm} = b_1$
-	Distance between the centre of corner bars parallel to the depth	=	$80 - 2(5 + 1.25) = 67.5 \text{ cm} = d_1$

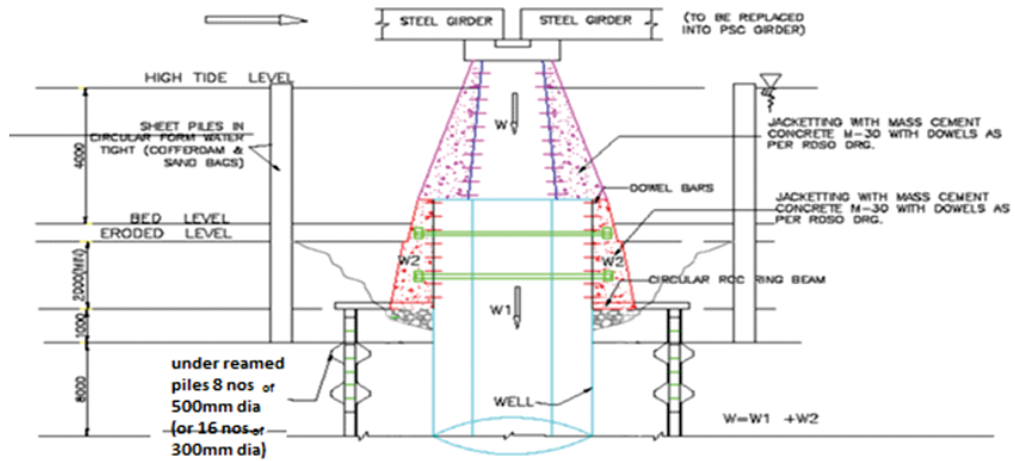
Transverse Reinforcement (Cl. 41.4.30 IS 456)

Two legged closed Loops enclosing the corner longitudinal bars shall have an Area of cross section

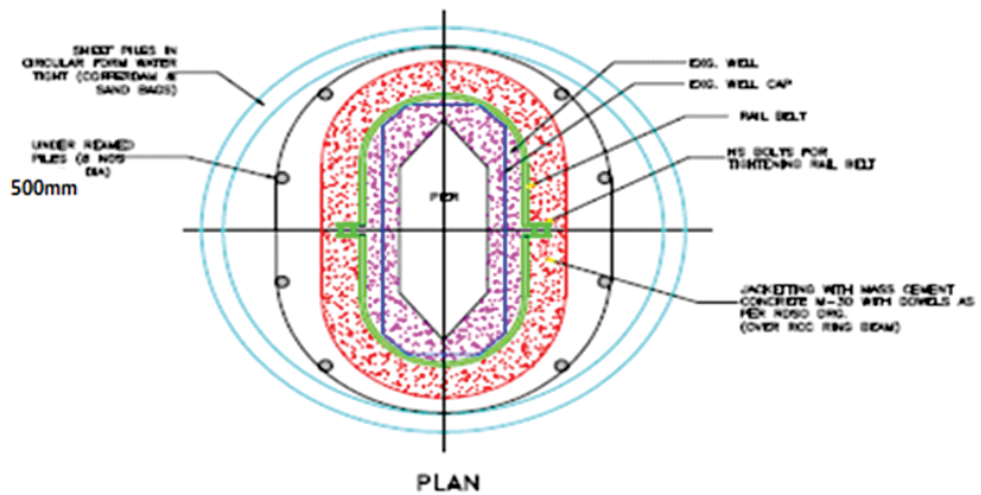
-	A_{sv} , given by	=	$(T S_v / b_1 d_1 \sigma_{sv}) + (V S_v / 2.5 d_1 \sigma_{sv})$
-	3.14	=	$0.073 S_v + 0.103 S_v$
-	Therefore, S_v	=	17.84 cm



Total traverse reinforcement shall not be less than			
-	$(Z_{ve} - Z_c) b. S_v / \sigma_{sv}$	=	$(10.51 - 3.26) (50) (15) / 1600.S_v$
-	Therefore, S_v	=	3.40 cm^2
-	Provide 10mm ϕ 4 –leg stirrups @ 150mm Centre to centre		
-	Steel for moment @ mid span		
-	Moment	=	9841 Kg m
-	$(9841 \times 100) / (2000 \times 0.894 \times 71.25)$	=	7.72 cm^2
-	Provide 4 / 16 Tor. Rod	=	8.03 cm^2
With 250 ϕ Piles (ALTERNATE)			
-	Min. Spacing	=	1.5 Du
-	Generally	=	2.0 Du
-	Du	=	$2.5 D = 2.5 \times 0.25 = 0.625\text{m}$
-	Spacing	=	$2 \times 0.625 = 1.25\text{m}$
With 16 No.s of double underreamed piles increase in capacity beyond 3.5m length			
-		=	$6.08 / 0.30 \times 1.15 = 23.31 \text{ t}$
-	Capacity of 1 pile	=	$18 + 23.31 = 41\text{t}$
-	Capacity of 16 No.s of piles (vertical load)	=	$16 \times 41 = 656 \text{ t} > 447 \text{ t}$
-	Capacity for lateral thrust	=	$16 \times 1.8 = 28.8 \text{ t}$ only $< 34.57 \text{ t}$. Inadequate.
-	Min. No.s of piles required. (from lateral load point of view)	=	20 O.K. since capacity is $20 \times 18 = 36\text{t}$. Hence ok.
-	Min. Spacing	=	$1.5 \times 0.625 = 0.94 \text{ m}$
-	21/ 20	=	1.05m spacing
Adopt 16 No.s. of 300mm ϕ U/R piles (Instead of 250 mm ϕ)			



SECTIONAL ELEVATION



PLAN

RAIL BELT REINFORCED BUTTRESS R/WALL FOR WELL FOUNDATION
TYPE: 3



8. Design of holding belt (size & number):

Holding belts made up of ISLC/ISMC or IS angles or FF/BB rails are designed to carry vertical shear force and contact area along the circumference of the well. Size and number are arrived based on the concept of distribution of shear force over the bearing area of jacketed concrete.

9. Checking the Adequacy of design:

i) Resistance of Soil at the scour at bed level

Recommendations for estimating the Resistance of Soil below the maximum scour level and checking safety in the design of well foundations of bridges are detailed in IRC : 45 – 1972.

IRC 45 in Annexure I, describes the elastic theory method and in Annexure II the ultimate soil resistance method for arriving at the resistance of soil. Ultimate soil resistance method is more opt in the case of well foundations since elastic failure is a common failure that is occurring due to sinkage or tilt of wells.

In ultimate soil resistance method, the soil around the base in either case slides over a circular cylindrical path with centre of rotation somewhere above the base. The plastic flow at the side follows the usual concept as in the case of rigid bulkhead at failure. Failure has been observed to occur at about 3° rotation of the well in case of non-cohesive soils.

ii) The factors to be considered in arriving at the likely pressure at these covered bed level are

- a) Movement of the point of rotation on the vertical axis
 - i. Effect of geometry and horizontal loads
 - ii. Effect of direct loads.
- b) Shift of the point of rotation along the horizontal axis.

iii) Method of checking and factors to be calculated:

- 1. Base Resisting Moment (M_b)-Moment of frictional forces mobilised
- 2. Side Resisting Moment (M_s)-Due to ultimate soil pressure distribution at front & back
- 3. Resisting moment due to friction on front and back faces (M_f) =



$$0.11 r (K_p - K_a) B^2 D^2 \sin \delta$$

- K_p & K_a are active and passive pressure coefficients, B is width of base parallel to the direction of train movement and δ is angle of wall friction.
- 4. Total resisting moment of soil $M_r = M_b + M_s + M_F$.
- 5. Factor of Safety, $= \lambda / \sum Y_i / M_r$.

10. Retrofitting Of Wells of BR.NO.482 (Span -7 X 12.20m) - Tirunelveli - Nagercoil section (Nambi River)

The Problem:

- Due to sand mining by local villagers the well foundation has a deep scour of 3m.
- Very tall bridge with 7.5m pier above the well.
- Well resting on silty sandy bed.
- Steep bed slope and heavy water flow.

WELL FOUNDATION REST ON SILTY SAND:



WELL FOUNDATION Retrofitted with U/R PILES- DOUBLE REAMED

11. Conclusion:

By adoption of this new and efficient technique of retrofitting of old well foundations at an optimal cost, heavy axle load trains and high speed trains can be operated advantageously without the necessity for rebuilding these important bridges over the Indian railways.