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Comparative Study & Design Optimization Of Rob Pier Pile Foundation With Bow String Girder Superstructure

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Abstract – This study examines the cost-effectiveness and design optimization of Pile Foundation of Pier of Road Over Bridge (ROB) with Bow String Girder superstructure. Optimum and safe design of Bridge especially in case of Bow String Girder Superstructure is very challenging task.

For this study ROB pier with wall type substructure and Bow String Girder superstructure of 64m span RDSO standard drawing RDSO/B-10427 and 4 lane carriageway adopted. Pile foundation of 10 Piles group with 1.2m dia of pile adopted.

For this IRC loading applied such as live load (4 lanes of Class A, 2 Lane of Class A+1 Lane of 70R, 1 Lane of 70R, 3 Lane of Class A, Special Vehicle Loading), Seismic Loading, wind load, dead load, wearing coat, crash barrier etc. FEM analysis done to get the benefit of design software to achieve the best results. Structure lies in the seismic Zone IV, so it is very important to study the effects of seismic loading over the structure and ultimately over the foundation.

Analysis covered the pier width varies from 6m to 12m. Results showed that with increase in the pier width pile reinforcement increases from 1.99% to 2.36%. In another study pier width kept constant and thickness keep changing from 0.90m to 1.5m. In this case pile reinforcement changes from 2.13% to 2.36%. These variations occur mainly due to changes in seismic forces.

Keywords- Pile, Pier, Seismic force, Bending Moment, Finite Element Analysis.

1. INTRODUCTION

Bow String girder is an arch bridge. Whenever the highway alignment passes over the railway lines a bridge needs to be proposed over the railway tracks for free flow of traffic and that bridge is called Road over Bridge (ROB). If the span of proposed bridge is less than 50m composite plate girder can be proposed, but if the span is of 50m or exceeds the 50m length then Bow String girder is proposed.

The substructure height over which the Bowstring girder rested, depends on the vertical clearance between the girder soffit and rail top levels. Railway department specifies the vertical clearance minimum 6.5m, in some cases it may be vary unto 7.5m. For ROBs wall type pier are preferred because the wall type piers offer more resistance to accidental load that is necessary to check for ROB pier as per railway standards. However, in some cases Portal frame type pier with circular column 2 or 3 numbers are also provided.

Pile foundations are mostly preferred and recommended for such heavy load. Because pile foundations offer more safe load bearing capacity than open foundation. Pile foundations are safer for such heavy dead load, live load and seismic loads. Pile foundations transfer the load safely to deeper hard strata.

2. LITERATURE REVIEW

Patel Nirav M, Prof. Deepa H. Raval [1] studied the design and economic aspects of tall pier and foundation of bridge. They mainly studied the effects of parametric changes such as pier height, concrete grade, reinforcement grade, substructure type, reinforcement dia etc. and finally studied the cost effects of all the parametric changes. The study

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based on IRC and IS code specifications. Is also studied the seismic effects on pier and foundation. Study used STAAD Pro software for FEM analysis. Analysis conducted on 6 different heights of pier ranges from 30m to 100m (30m, 50m, 70m, 80m, 90m and 100m).

Though this studied the bridge pier and its foundation for different heights, the superstructure span (25m) is not so large. So, the study lacks the heavy superstructure load and pile foundation parameter are not defined clearly and the study mainly focused on the substructure.

Makoto Kimura, Shinya Inazumi, Yoshikazu Nishiyama, Hirikuni, Masanori Kobayashi, Masami Ochiai [2] This study presents the development and potential of newly developed H-joint steel pipe sheet piles of bridge pier foundation. This study shows how the steel pipe sheet piles (SPSP) are developed, tested before use and the site execution. The findings of the study are listed as: i) these type piles are installed with high driving pressure. ii) The joints of the sheet piles are strong in bending. iii) due to high rigidity lateral bearing capacity is high. iv) helps in reducing the number of piles and labour cost.

The study doesn't depict the superstructure & substructure load for which the sheets piles are designed for bridge piers. It also not specifies the H – section properties used for the joint, which is the main element of these types of piles. Though it presents the different method and material for bridge pier foundation piles, but are not so viable than the conventional RCC bored cast-in-situ piles.

Seungho Kim, Sangyong, Seoung-Wook Whang, Won Gil Hyung [3] This study explains the application of extended end composite pile. This work mainly focused on foundation of high-rise buildings. For the sake of safety of and high bearing capacity, pretensioned high strength concrete piles (PHC) have been put to practical use. However, PHC piles have limited bearing capacity, leading to the congested layout and thus finally results in high construction cost. To overcome this steel PHC composite piles have been developed. These types of piles have low cost and high bearing capacity. Other type of piles known as extended end pile have high bearing capacity.

Though these types of piles have high bearing capacity, however the research work done on building site and there is no study for seismic forces and bridge foundation.

Prakriti Sharma B. Eng. Pokhara University, 2015 [4] This study based on the comparative study of different methods for superstructure-foundation interactions. Soil -pile interaction by STAAD software analysis completed. A case study of 3x24.4m with pile foundation adopted. Propertied of soil at different layers assigned as spring constant. Superstructure response represented by bending moment and deflection. Different design / analysis approaches are discussed in this study such as Integrated analysis process (IAP) Simplified Boundary Condition (SBC) approach, Maximum allowable displacement (MAD) approach, equivalent pile length (EPL) approach.

In IAP method substructure and superstructure elements were analysed holistic approach whereas in other methods superstructure and foundation are analysed separately.

Gianpiero Russo [5] Analysis and design of pile foundations under vertical load is studied under this research. Load sharing and interaction between the piles and connecting raft is a key factor in optimum design. In this study the effects of installation technique discussed on the basis of experimental data received from different sites. Bearing capacity-based design and settlement-based design are compared to find which one method is more suitable for optimum design.

The installation technique on pile performance under vertical load. The performance mainly depends on the dia of pile, surrounding soil characteristics and vertical load coming over it. Though this study discusses the pile behaviour subjected to vertical load in building structure, it doesn't discuss about pile foundation of bridge structure.

3. BRIDGE INPUT DATA

The bridge input data used for analysis listed as below:

Main ROB Span:	64.000m (RDSO/B-10427)
Pier:	12.0x1.2m (Wall Type)
Pile:	1.2m Dia, 10 Piles

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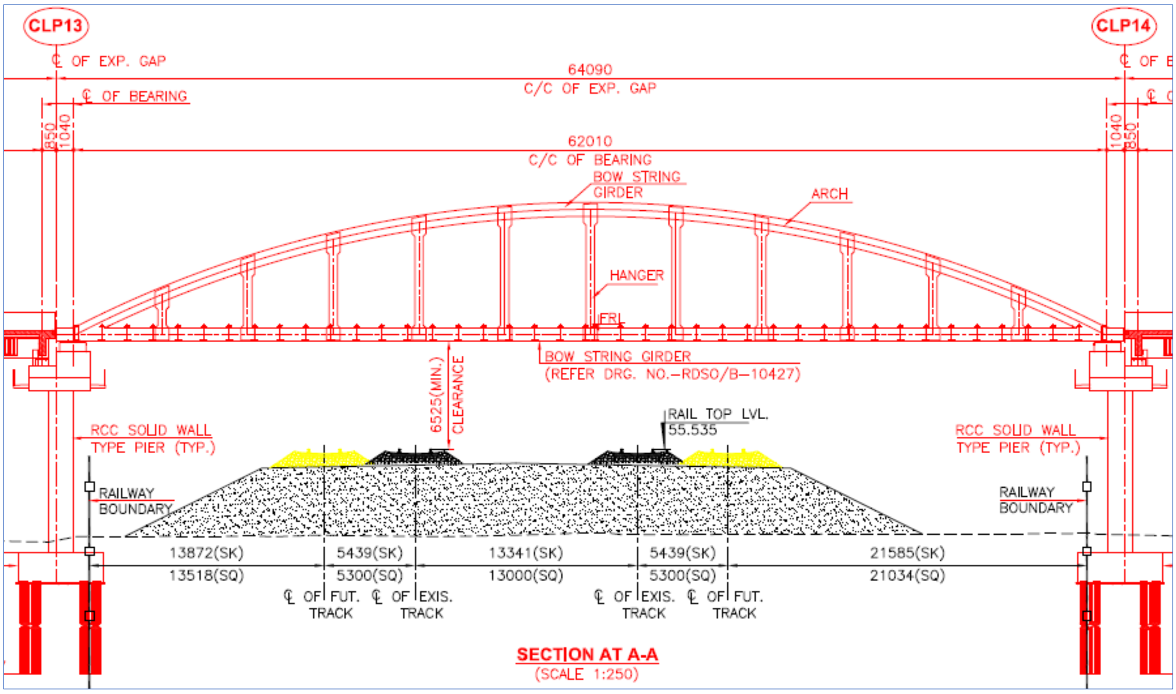

Fig.1-Details of ROB Span Bow String Girder

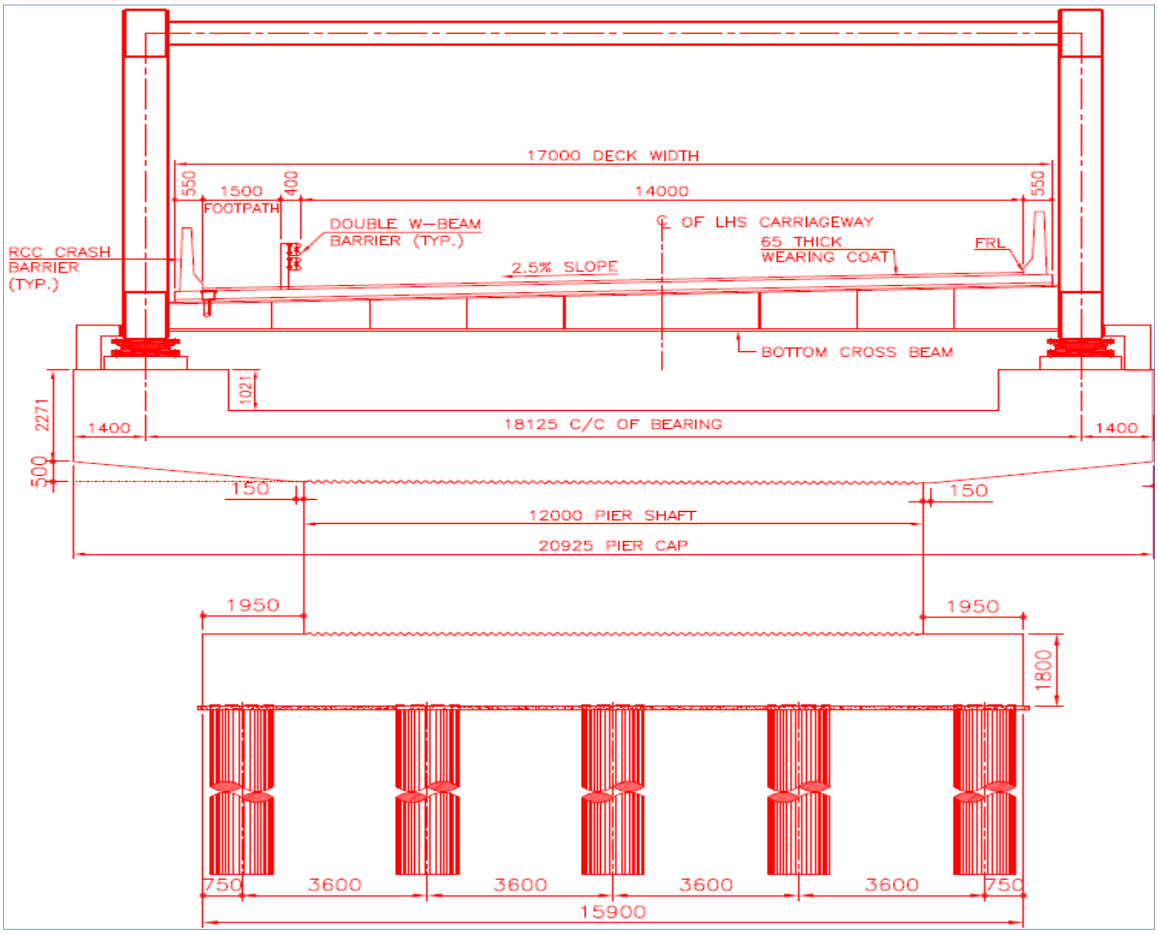

Fig.2 Details of Pier Cross Section

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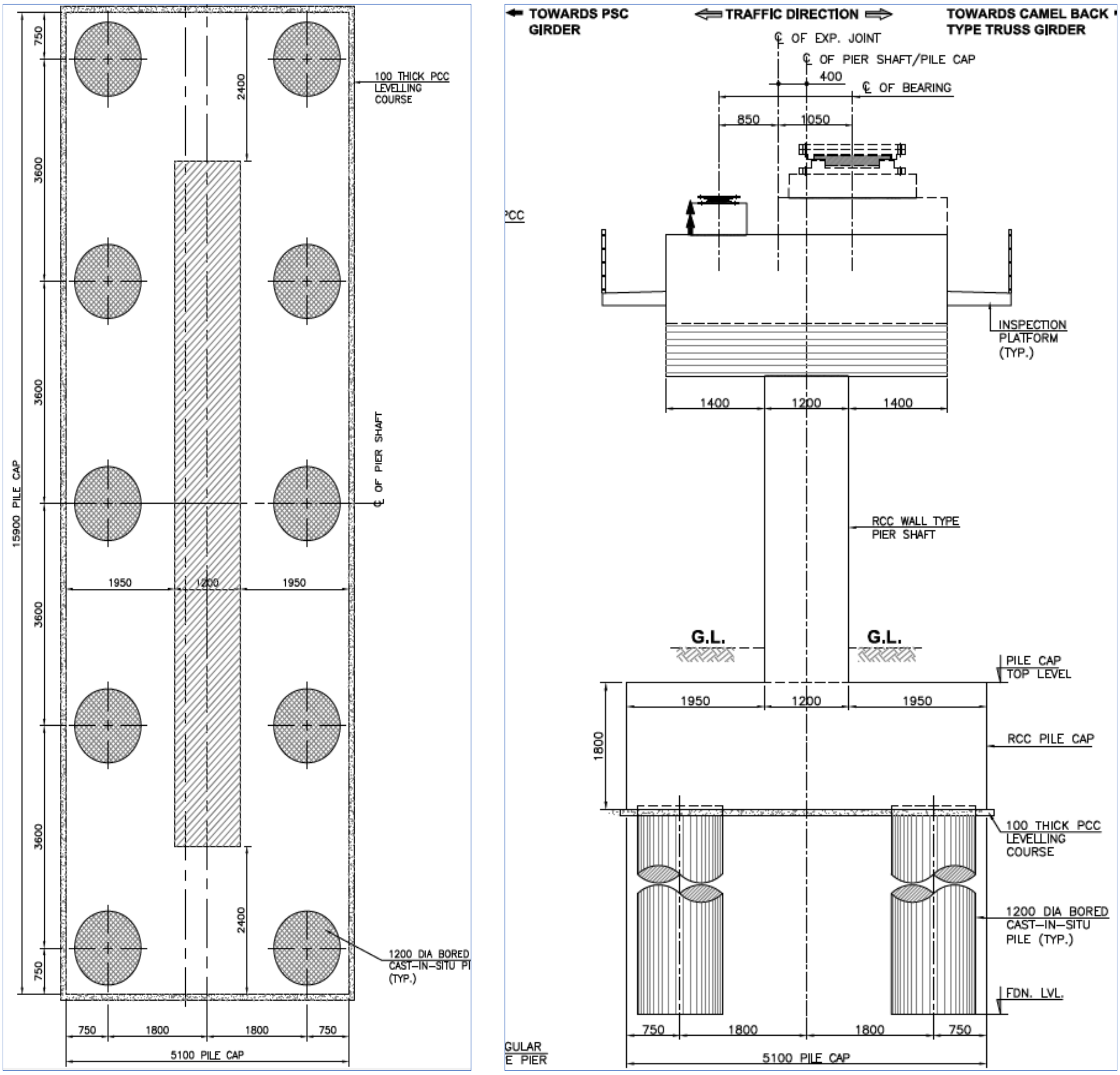

Fig.3 Details of Pile Group and Pier Elevation

4. METHODOLOGY

For the analysis FEM model is prepared in the STAAD pro as per the pier specifications. Pile and pier are modelled in the software. Spring constant applied as per the Geotech exploration SPT N values and IS:2911 (Part1/Sec2):2010. Once the model is complete apply 1000kN load in longitudinal and transverse direction for stiffness calculation. On the basis of stiffness time period and seismic coefficient and seismic forces calculated. To optimize the pile foundation seismic forces should calculated carefully, because in this analysis, seismic load combination is governing one.

Following load data used for the analysis:
Dead load Superstructure: As per RDSO/B-10427
Crash Barries: 1.5t/m
Wearing Coat: 0.2t/m^2
Seismic Zone (Z): IV
Importance Factor (I): 1.2
Live Load: As per IRC:6-2017

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The results obtained from the analysis tabulated in the table 1 & 2

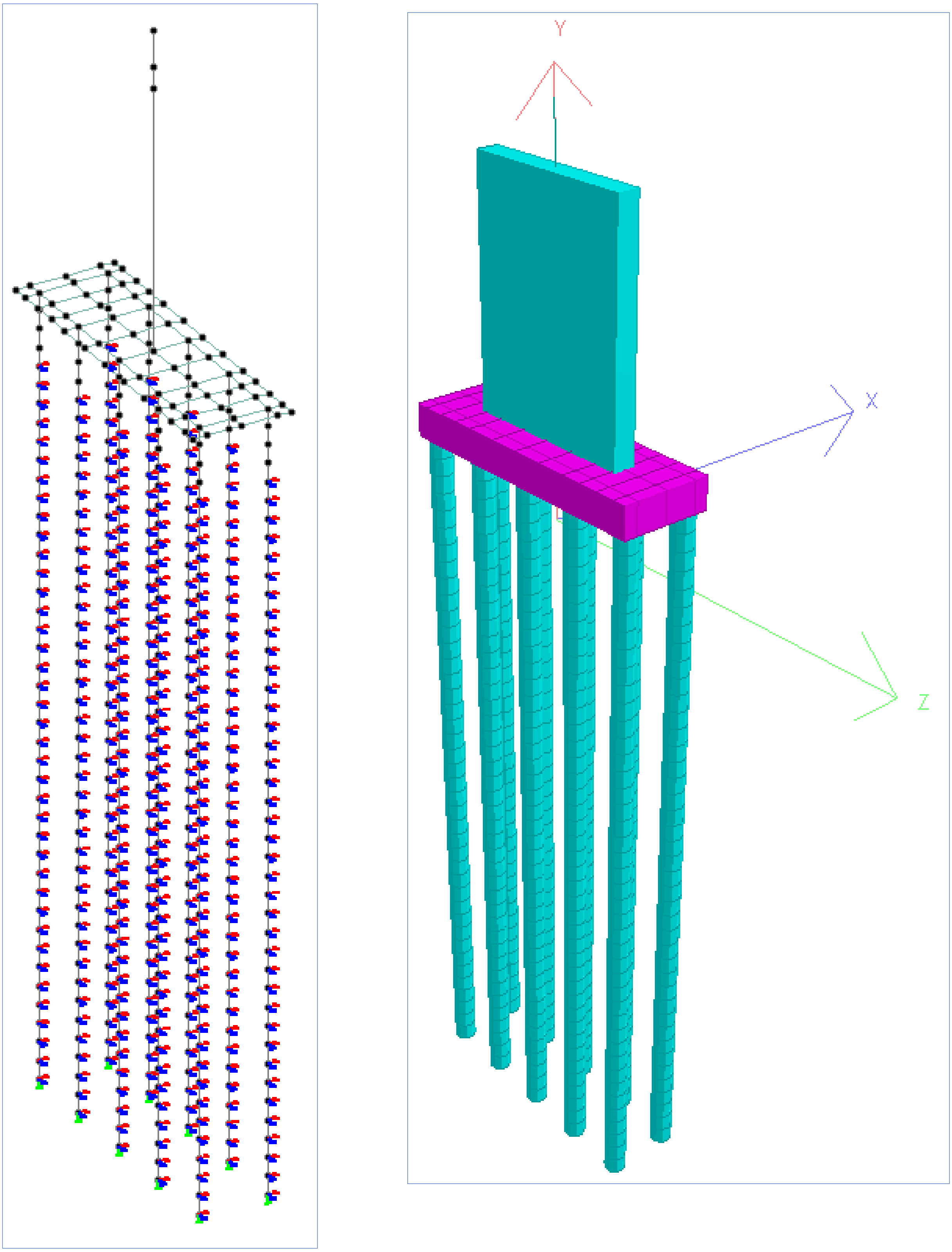

Fig. 4 3D FEM Model of Pier with Pile Foundation

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TABLE 1: MAXIMUM & MINIMUM REACTION OVER PILE

S.No.	Pile Reaction over Pile No.												t horizontal force
	1	2	3	4	5	6	7	8	9	10	11	12	
	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne	Tonne
LC-1	205	205	205	205	205	466	466	466	466	466			8.0
LC-2	319	319	319	319	319	460	460	460	460	460			6.1
LC-3	282	293	303	313	324	546	556	566	577	587			12.1
LC-4	279	289	300	311	321	551	561	572	583	594			11.2
LC-5	139	139	139	139	139	347	347	347	347	347			6.9
LC-6	227	227	227	227	227	344	344	344	344	344			5.3
LC-7	195	204	213	222	231	418	427	436	445	454			10.4
LC-8	192	201	211	220	229	423	432	441	450	460			9.7
LC-9	134	151	169	186	204	445	463	480	498	516			16.7
LC-10	97	156	215	273	332	317	376	435	493	552			35.4
LC-11	146	163	181	198	216	461	479	496	514	532			16.7
LC-12	109	168	227	285	344	333	392	450	509	568			35.4
LC-13	90	134	178	222	265	481	525	569	613	656			33.8
LC-14	-22	123	269	415	561	185	331	477	623	769			81.1
LC-15	122	165	209	253	297	514	558	602	646	689			33.8
LC-16	9	155	301	447	592	218	364	510	656	802			81.1
LC-17	133	179	225	272	318	440	486	533	579	625			31.2
LC-18	14	165	317	468	620	138	290	441	593	744			82.1
LC-19	164	211	257	304	350	473	520	566	613	659			31.2
LC-20	45	197	349	500	652	171	323	475	627	778			82.1
LC-21	131	178	224	270	317	441	488	534	581	627			31.2
LC-22	12	164	316	467	619	139	291	443	595	746			82.2
LC-23	162	209	256	302	349	475	522	568	615	662			31.2
LC-24	43	195	347	499	651	173	325	477	629	780			82.2
LC-25	352	353	355	356	358	495	496	498	500	501			6.1
LC-26	337	338	339	341	342	504	505	507	508	509			6.1
CAPACITY DESIGN													
LC-29	-85	-67	-50	-32	-15	664	681	699	717	734			48.5
LC-30	-71	-54	-36	-18	-1	678	695	713	731	748			48.5
LC-31	-89	-45	-1	43	86	660	704	748	791	835			53.2
LC-32	-57	-13	31	75	119	692	736	780	824	867			53.2
LC-33	-88	-42	5	51	97	661	707	753	800	846			53.4
LC-34	-56	-9	37	84	130	693	740	786	833	879			53.4
LC-35	-88	-42	5	51	98	661	707	754	800	847			53.4
LC-36	-56	-9	38	84	131	693	740	786	833	880			53.4

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TABLE 2 ULS Design Check for Pile

LC	Pile Reaction: Vertical Load Max (Tonne)	Pile Reaction: Vertical Load Min (Tonne)	Pile Reaction: Horizontal (Tonne)	Moment M_{ED}: M = Q (L1 + Lf)/2*m (Tm)	Moment M_{RD} From Intraction: Max N_{ED} (Tm)	Moment M_{RD} From Intraction: Min N_{ED}	Check ($M_{ED} < M_{RD}$)	(SHEAR CAPACITY (LONGITUDINAL DIR^{n})) $\sigma_{cp} = N_{ED}/A_c$ (N/mm^2)	V_{Rdc} (Tonne)	Check $H_L < V_{Rdc}$
LC-1	466	205	8	43	506	496	OK	4	70	OK
LC-2	460	319	7	38	506	512	OK	4	69	OK
LC-3	587	282	12	64	501	513	OK	5	82	OK
LC-4	594	279	11	60	501	513	OK	5	83	OK
LC-5	347	139	7	37	511	480	OK	3	58	OK
LC-6	344	227	6	33	511	501	OK	3	58	OK
LC-7	454	195	10	55	506	494	OK	4	69	OK
LC-8	460	192	10	52	506	493	OK	4	69	OK
LC-9	516	134	17	89	504	478	OK	5	75	OK
LC-10	552	97	35	188	503	469	OK	5	79	OK
LC-11	532	146	17	89	503	481	OK	5	77	OK
LC-12	568	109	35	188	502	472	OK	5	80	OK
LC-13	656	90	34	179	498	468	OK	6	89	OK
LC-14	769	-22	81	431	494	440	OK	7	101	OK
LC-15	689	122	34	179	497	475	OK	6	93	OK
LC-16	802	9	81	431	493	448	OK	7	104	OK
LC-17	625	133	31	165	500	478	OK	6	86	OK
LC-18	744	14	82	436	495	449	OK	7	98	OK
LC-19	659	164	31	165	498	486	OK	6	89	OK
LC-20	778	45	82	436	494	457	OK	7	101	OK
LC-21	627	131	31	165	500	478	OK	6	86	OK
LC-22	746	12	82	436	495	449	OK	7	98	OK
LC-23	662	162	31	165	498	485	OK	6	90	OK
LC-24	780	43	82	436	494	456	OK	7	102	OK
LC-25	501	352	6	33	505	510	OK	4	74	OK
LC-26	509	337	6	33	504	511	OK	5	74	OK
CAPACITY DESIGN										
LC-29	734	-85	49	258	495	425	OK	6	97	OK
LC-30	748	-71	49	258	495	428	OK	7	98	OK
LC-31	835	-89	53	282	491	424	OK	7	107	OK
LC-32	867	-57	53	282	490	432	OK	8	110	OK
LC-33	846	-88	53	284	491	424	OK	7	108	OK
LC-34	879	-56	53	284	490	432	OK	8	112	OK
LC-35	847	-88	53	284	491	424	OK	7	108	OK
LC-36	880	-56	53	284	490	432	OK	8	112	OK

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5. RESULTS & DISCUSSIONS

For the pile optimization motive, different iterations are done with the pier parameters changes. In first trial pier width vary from 12.0m to 6.0m and in another trial thickness changes from 1.5m to 0.9m. If only the pile reinforcement and pile cost considered then 1.2x6.0m is the most economical combination. However, in case of Bow String Girder for 17.0m width carriageway with 18.125m bearing to bearing transverse pier cap is almost 21.0m. For such large pier cap 6.0m pier width is too short because in this case pier cap cantilever will be 7.50m. For bow string girder of 64m span such large pier cap cantilever is not feasible. So, 1.2x10.0m pier shaft is best pier dimension.

Results Presentation with Different Iterations

Table 3: Summary of Results ; Pier Thickness kept same 1.2m

S. No.	Pier Size (m)	Interaction Ratio	Area of Reinforcement (mm^2)	% age of Reinforcement
		Pile	Pile	Pile
1	12.00	0.91	26678	2.36
2	11.00	0.91	26364	2.33
3	10.00	0.91	25384	2.24
4	9.00	0.91	25070	2.22
5	8.00	0.91	24127	2.13
6	7.00	0.91	23461	2.07
7	6.00	0.91	22481	1.99

Table 4: Summary of Results ; Pier Width kept same 10.0m

S. No.	Pier Thickness (m)	Interaction Ratio	Area of Reinforcement (mm^2)	% age of Reinforcement
		Pile	Pile	Pile
1	1.50	0.92	26641	2.36
2	1.40	0.91	26012	2.30
3	1.30	0.92	25384	2.24
4	1.20	0.92	25070	2.22
5	1.10	0.93	24756	2.19
6	1.00	0.93	24442	2.16
7	0.90	0.93	24127	2.13

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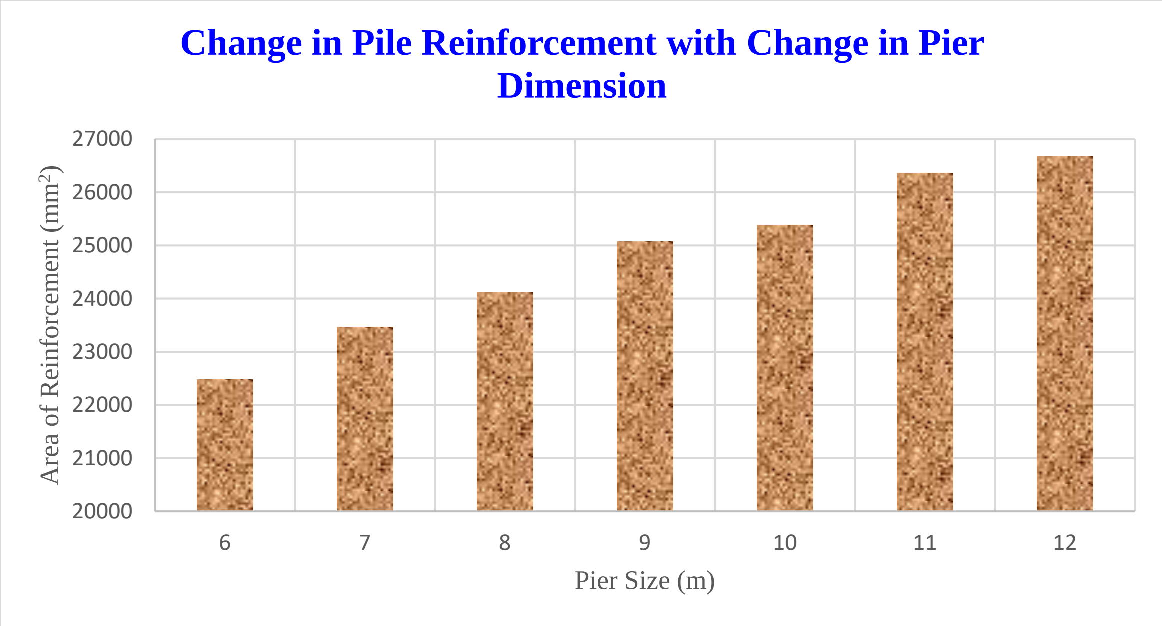

Fig. 5 Change in Pile Reinforcement area w.r.t. Pier Dimension

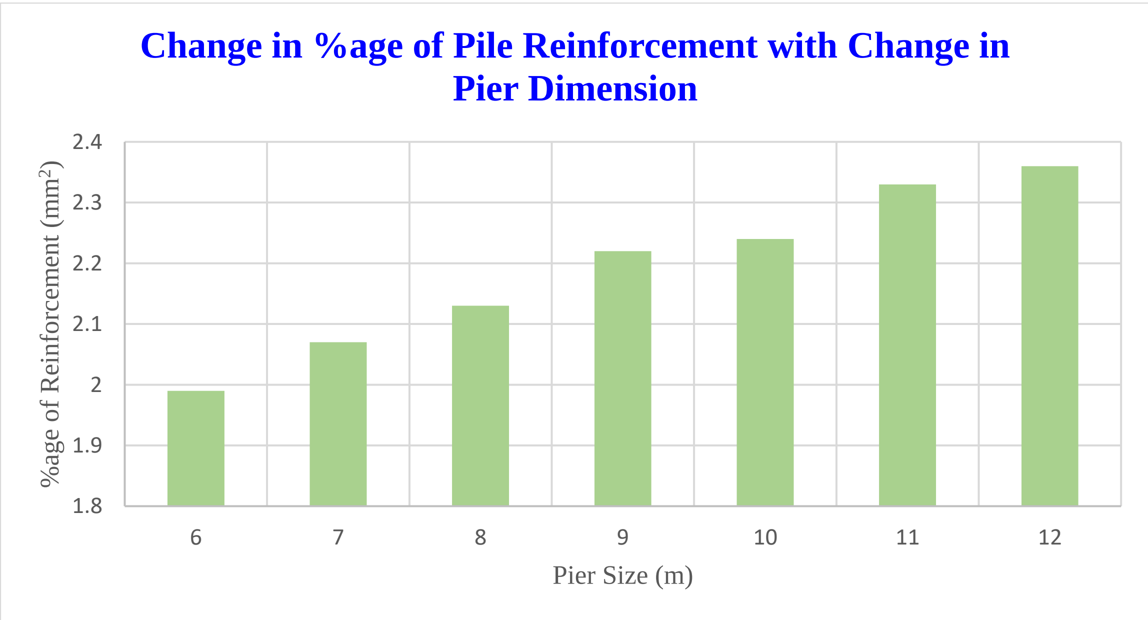

Fig. 6 Change in Pile Reinforcement %age w.r.t. Pier Dimension

6. CONCLUSION

After the parametric study of Bridge pier to analyse the effect on pile foundation, it is found that with the increase in the pier width or thickness pile reinforcement also increases. It happens because with the increase in pier size pier stiffness increases that reduced the seismic time period and increase the Sa/g value and ultimately the seismic coefficient and seismic forces which causes to increase the pile reinforcement.

7. REFERENCES

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