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OPTIMIZATION OF PIER SHAPES FOR BRIDGES

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Abstract— Now- a- days many bridges are constructed on slender piers to provide adequate stiffness and strength with substantial saving of dead load where the reduction in dead load by choosing optimum shape of pier can facilitate applicable savings in foundation cost. Use of hollow pier construction could produce great savings in foundation cost. In this study, pier model has been analyzed using FEM in SAP. Maximum principal stresses and Von misses stresses are calculated for different types of pier shapes using SAP-2000 software. In this study we found that rectangular sections are economical when compared to other sections. Several iterations have been carried out for making pier hollow and is analysed for the variation of the stresses. Hollow cross sections are made at the core of the cross sections. The stress level in the solid pier and hollow pier are nearly same and it proves that the hollow sections act same as the solid section.

Index Terms— SAP-2000, Finite element analysis, Solid pier, Hollow pier, Stresses.

1 INTRODUCTION

Piers are designed to resist the vertical loads from the super structure, as well as the horizontal loads not resisted by the abutments. The shape of the pier depends upon the size and dimensions of the super structure. Piers can be solid or hollow in cross section. Solid piers are of mass concrete or masonry. Hollow concrete pier provide advantages for the structural design compared to solid pier. Seismic design forces produced by self weight of structure and the heat of hydration produced by Portland cement can be decreased by the reduction in volume of pier, which results in mitigating cracking of concrete. When a hollow cross section exceeds a width to depth ratio 3, the cost of extra formwork probably exceeds the material savings, but the reduction in dead load can still produce appreciable savings in foundation cost. Such savings can be quite substantial, depending upon the geometric configuration of the cross section. Slip form construction techniques are well suited to hollow or cellular pier construction. The magnitude of the superstructure loads applied to each pier shall consider the configuration of the bearings, the bearing type and the relative stiffness of the entire pier. The analysis to determine the horizontal loads applied at each pier must consider the entire system of piers and abutments and not just the individual pier.

1.1 HOLLOW CROSS SECTION CONFINEMENT:

Compression column elements potentially support a variety of structures such as bridge decks and floor slabs. Columns vary in physical shape depending on their application, although typically they are circular or rectangular, solid or hollow, for the simplicity of construction.

Hollow concrete cross sections are usually found in tall bridge piers. High elevation bridges with very large size columns are constructed to resist high moments and shear demands. In particular, bridge piers designed in accordance with old design codes may suffer severe damage during seismic events, caused by insufficient shear or flexural strength, low ductility and inadequate reinforcement detailing. Many parameters may influence the overall hollow column response such as: the shape of the section, the amount of the longitudinal and transverse reinforcement, cross section thickness, the axial load and finally the material strength of concrete and steel.

The hollow cross section shall be done by analyzing the stress in the each element by the theory of stresses, the element which has stresses of nearly zero magnitude means that, even if these elements are not present, there would not be any significance reduction in strength of the structure.

2 DETAILS OF STRUCTURE

2.1 MODELING AND ANALYSIS

The finite element method is a numerical technique for finding approximate solution to boundary values problems. The FEM is the dominant discretization technique in structural mechanics. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint components of simple geometry called finite elements. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function at a set of nodal points. The response of the mathematical model is considered to be approximated by that of the discrete model obtained by connecting or assembling the collection of all elements. In the present work, finite element analysis of different pier models has been carried out and meshing has been done by using SAP-2000 software to evaluate an optimum bridge pier shape.

A model represents can be built using the computer structural analysis programs, and set of inputs are given, such as loads, material characteristics, and geometry. And output, obtained such as stresses in piers, quantity of steel and concrete by using SAP-2000 program to create and analyze finite element model for pier, considering that there is compatibility between the model and the actual case. In order they represent a structural model for pier the following assumptions are used.

2.2 Modeling Assumptions

For The pier model dimensions are considered are size of the pier 1.5m x 1.5m, height of the pier 9m. Different types of pier models are square, rectangle and circular sections are considered. The material properties considered for pier analysis for concrete reinforcement and steel are as below.

Table 1 Properties of Concrete:

Compressive strength of concrete	35N/ mm^2
Elastic modulus of concrete	29580N/ mm^2
Density of concrete	23kN/ m^3
Poisson's ratio	0.2
Thermal expansion coefficient	1.17x 10-2/ 0C

Table 2 Properties of Reinforcing Steel:

Yield strength of steel	500N/ mm^2
Young's modulus of steel	205,000N/ mm^2
Density of steel	78.5kN/ m^3
Poisson's ratio	0.2
Thermal expansion coefficient	1.2x 10-2/ 0C

2.3 Design Load Estimation on Pier

The approximate loads estimation on pier is done as per IRC codal provisions. Some forces will act in combinations with other forces, thus there are different probable load combination, likely to act on pier, different load combinations are considered as mentioned by IRC and for the sever combination pier section is analyzed. The total loads on piers are considered for these designs are axial load – 4200 KN, Moment Y-direction – 5800 KNM.

3 Analysis and Response

To derive an optimum shape of the pier, the model is analyze with respect to various stress at all levels of the pier and the elements where the stress is very negligible, those elements need to be taken out and again run the analysis. In case there is no change in Von-misses stress, the process of deleting the elements is continued till the desired optimization is achieved.

4 Optimization of the Section by Analyzing Stress

The optimization of the section shall be done by analyzing the stress in the each element. As per the theory of stresses, the elements are not present there would not be any significance reduction in strength of the structure. Keeping this theory as a base, a trial shall be done by filtering out the elements which are having stress of zero magnitude.

There would not be any elements which has stress of zero magnitude. In this case, trails are done by filtering out the elements which has the stress levels between -0.5 KN/m^2 to +0.5 KN/m^2 and by increasing the range to –1KN/m^2 to +1KN/m^2. By considering the trail-2 model, filter the element which has the stresses ranging from -1KN/m^2 to +1KN/m^2.

5 Objective

A pier is modelled in SAP-2000, the stresses in the pier model is compared for the solid and the hollow section under the same loading condition. The shape and the volume of hollow portion of pier is arrived after performing iterations and only those hollow sections are considered in which the stresses in the pier remain constant or with very minimum change with respect to solid section. In case, the stresses in the bridge pier for solid section and finally arrived hollow section are similar, then it shall be proved that hollow section is as good as the solid section. In this paper procedure of modelling, loading, analyzing and comparing stresses of a pier in SAP-2000.

6 Results and Disscussion

Analysis is performed for all pier types using SAP-2000. Thus results are obtained for maximum principal stresses, von misses stresses, quantity of steel and concrete are given in the following tables.

Table 3 Chart Showing the Volume and Von Misses Stresses for Solid Pier Section:

SL/NO	Description	Section volume (cum)	Maximum principal stresses (KN/m^2)	Von misses stresses (KN/m^2)
1	Square	20.25	143218.66	318731.99
2	Circular	15.9	21444.88	82881.62
3	Rectangular	44.25	14335.9	318781

Table 4 Quantity of Steel

Pier type	No of bars	Length (m)	Area (m^2)	Density kg/m^3	Quantity steel (Kg)
Square	64	9	0.00025	7850	1130.4
Circular	79	9	0.00025	7850	1395.3
Rectan-gular	56	9	0.00025	7850	989.1

TABLE 5 QUANTITY OF CONCRETE AND STEEL FOR SOLID PIER SECTION

Section	Quantity of steel (kg)	Quantity of concrete (m^3)
Square	1130.4	20.25
Circular	1395.3	15.9
Rectangular	989.1	44.55

When compared to square section von misses stresses for circular section decreases by 74% and negligible difference for rectangular section. It is observed that, for circular section even though there is a decrease in volume by 21.5% compared to square section quantity of steel increases by 23.43% compare to rectangular section. It can be concluded from this results that shape of the pier plays a major role with the same loading conditions rectangular section is the optimum section with minimum quantity of steel compared to other two sections.

The section can be further optimized by analyzing the stress distribution pattern across the section. By keeping the theory of stresses as a base it is observed that there are few elements in the pier section which are un-stressed therefore trials are performed by creating hollow sections and results are obtained by following table.

TABLE 6 Chart showing the savings on the hollow sections, increase in the maximum principal stress and von misses stress for the pier section

SL/NO	Description	Section voume (cum)	Hollow section voume (cum)	Maxmum principal stresses (KN/m^2)	Von-misses stress (KN/m^2)
1	Square solid model	20.25	0	143218.66	318731.99
2	Square hollow trial-1	18.063	2.187	143218.65	318731.98
3	Square hollow trial-2	17.577	2.673	143218.2	318731.98
4	Square hollow trial-3	16.605	3.645	143216.34	318731.16
5	Circular solid model	15.9	0	21444.88	82881.62
6	Circular hollow trial-1	11.48	4.42	21445.27	82881.47
7	Circular hollow trial-2	9.72	6.18	21445.42	82879.93
8	Circular hollow trial-3	7.95	7.95	21431.44	82861.69

For hollow square section there is a reduction in volume by 18% compared to solid section but there is no change in the stresses. For circular hollow section there is a reduction in volume by 50% compared to solid section but there is no much change in the stresses with same loading conditions. Even though there is a reduction of 50% in volume as hollow section, but there is a negligible increase in the stresses. With the hollow section, it is not that only concrete is saved, a considerable quantity of steel is also saved proportionate to the hollow volume. Concrete and steel quantity required for the foundation is also reduced due to the decreased dead weight of hollow section.

7 Conclusion

In this study, the stresses of the concrete pier are analyzed by finite element method. Model is analyzed using the set of data considered for preparing pier model and compared to different pier shapes. After analyzing the results for each analysis the following conclusions can be drawn.

From the results it can be concluded that shape of the pier plays a major role with the same loading conditions, rectangular section is the optimum pier section compared to other two sections.

It is observed that there are few elements in the pier section which are un-stressed and taking out these elements shall not affect the strength of the pier.

Even though there is a reduction of 50% volume in hollow section but there is negligible increase in the stresses.

Due to the hollow section, the load on the foundation reduces compared to full solid section, thus a direct savings in foundation

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cost.

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