

OPTIMIZATION OF REINFORCED CONCRETE ENCASEMENT TO HUME PIPE CULVERTS USING FINITE ELEMENTS BASED ANALYSIS

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Introduction

This paper summaries the non-linear finite element based analytical procedure carried out to optimize the top and bottom thickness of reinforced concrete encasement for circular Hume Pipe culverts with 900 mm , subjected to HA and HB type of loadings specified in BS 5400: Part 2: Specifications for Loads applicable to highways in Sri Lanka.

Methodology

First, a finite element model was developed with 8-node hexahedrons to stimulate the Three-Edge Bearing Test of SLS 452:1979 to obtain the load deflection curve for Hume Pipe alone and also to determine the maximum tensile and compressive stresses at the serviceability limit state (SLS) and ultimate limit state (ULS) conditions. The software package used for this purpose was *MIDAS FE* and a view of the model is shown in Fig. 2. Accordingly the material nonlinearity of concrete and reinforcing steel of the Hume Pipe are represented by the *total crack strain model* and the *Von Mises* yield criteria respectively. The total strain crack model is classified under the smeared crack model and it

provides two methods, which are separated into the fixed crack model and the rotating crack model depending on the reference crack axes. The results obtained from the numerical analysis procedure were compared with the values given in SLS 452:1979 to validate the model.

Secondly, for the detailed investigation of the performance of Hume Pipe culvert with reinforced concrete surrounding (Fig.3), five different configurations (Table.1) were analysis by varying the parameters A and B and the diameter of the Hume Pipe (Fig.1). The concrete units are refined into the approximate mesh size of 60x60x25mm to have a well define Jacobean matrix in the model (total number of brick elements =247892 and total number of DOFs = 866058). It is important to highlight that each of the FE model is analyzed for the applied gravity and imposed loads together with the appropriate safety factors to achieve the SLS and ULS conditions. Finally, the variations of maximum tensile and compressive stresses were plotted against the applied load for each model developed pertaining to the five case studies as shown in **Table 1**.

Results and Discussion

The graph shown in Fig.4 illustrates the load deflection curve obtained by numerically simulating the *Three Edge Bearing Test* as per *SLS 452:1979*. The two horizontal lines show the limits indicated in the standard for SLS and the ULS respectively. According to the results that initiation of tensile crack in concrete and the yielding of embedded reinforcements are observed at the external loads of 18.5 kN/m and 43.1 kN/m respectively. Hence, it proves the capability of numerical model in predicting the response accurately under the static loading condition. For each case study, the stress distributions of S_{xx} , S_{zz} , $P1$ and $P3$ ($P1$ and $P3$ are the direction of principle stress) were obtained under the serviceability limit state and compared with corresponding limiting values, as shown in Fig.5. It was observed that the main factor which influence the load carrying capacity are the tensile strength of concrete. Further, in all the cases, except in configuration 1 where A is equal to 100 mm, the peak principle tensile stresses at the serviceability limit state are well below the maximum tensile

stress for concrete cracking. The load applied to the pipe culvert was increased gradually until failure to observe the load carrying capacity with surrounding thickness. The ratio of maximum load carrying capacity to 100 kN was found to be 1.2 to 2.2 for A=100 to 275 mm, with B= 175 mm and the results are shown in Table 2.

Conclusion

This study was carried out to optimize the dimensions of the reinforced concrete encasement to 900 mm diameter concrete hump pipes, when used as pipe culverts. Results indicated that for 900 mm Hume Pipes A= 150 mm and B= 175 mm give the optimum results, in terms of strength and durability. This is for concrete grade 20. However, higher concrete grade does not improve the results appreciably, as the failure is mainly governed by the yielding of circumferential reinforcement in the Hume Pipe. The study also demonstrates the possibility of using accurate numerical techniques to obtain cost benefits in large projects by optimizing the dimensions of the structures.

Table 1. Five different configurations

Case study.	Parameter A/(mm)	Parameter B/(mm)
1	100	100
2	100	175
3	150	175
4	200	175
5	275	175

Table 2. Load carrying capacity of different configurations

Case study	Tensile stress at 100 kN/ (MPa)	Maximum load bearing capacity	Ratio of load carrying capacity to 100 kN
1	1.86	120	1.2
2	1.76	125	1.25
3	1.39	160	1.6
4	1.16	185	1.85
5	0.31	220	2.2

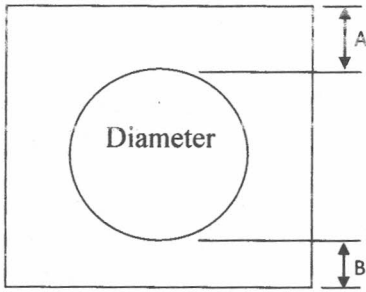


Fig.1. Definition of parameters

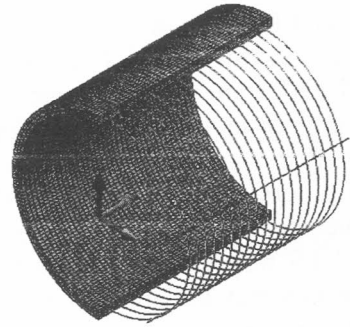


Fig.2. Finite element model of hume pipe only: un-deformed geometry

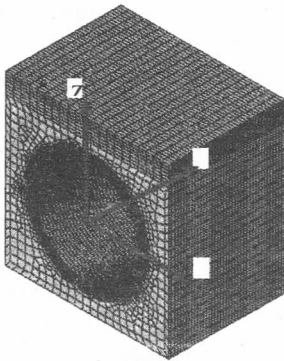


Fig.3. Finite element model of hume pipe culvert with concrete surrounding

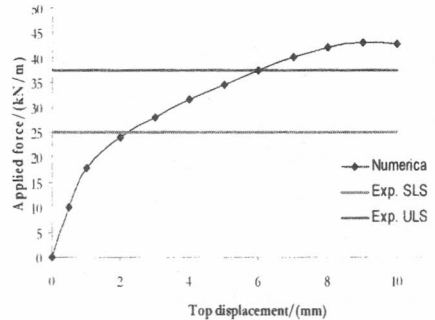
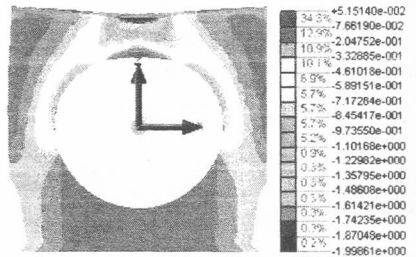
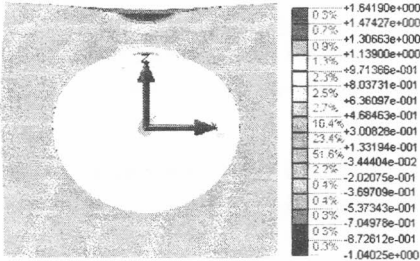


Fig.4. Load-deflection curve of 900 mm hume pipe, under 3-edge bearing test



References

SLS 452, Specification for Concrete Non-Pressure Pipes, Bureau of Ceylon Standard, 1978.
 BS 5400, part 2, Specifications of Loads, British Standard, 1978.