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Finite Element Analysis of Shear Critical Thin-Walled Reinforced Concrete Structures

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Abstract: *Cyclic Softened Membrane Model (CSMM) is one such promising model that can accurately capture these effects in structures subjected to quasi-static and transient loads. However, the existing finite implementation of CSMM model in Open SEES is not robust to completely analyze RC wall type structures under all type of loads. Several issues related to the numerical stability (or non-convergence issues) of CSMM based nonlinear finite element model have been reported in the literature. Hence, the present study has been conducted to explore the reasons associated with these numerical issues and develop an improved CSMM model that can accurately capture the complete nonlinear behaviour of RC wall type structures under all type of loads. The present study can be categorised into three stages, namely development, validation and application. In the development stage, a new improved CSMM model has been developed and implemented in the Open SEES finite element framework. In the application stage, the thoroughly validated improved CSMM based A FEM was employed to conduct Integrated Dynamical Assessment (IDA) and subsequently generate high-resolution fracture characteristics for 3 hollowed square reinforced concrete bridge piers utilising the Maximising Probability Estimating (MLE) approach. The constructed curves for fragility have been juxtaposed with those derived from 1D fiber-dependent regressive boundary component analysis to investigate the influence of pinching effect and stiffness degradation of the bridge piers on the fragility curves..*

Keywords: Reinforced Concrete, Wall-Type Structures, Thin-Walled Systems, FEA, Plane Stress Elements

I. INTRODUCTION

Thin-walled reinforced concrete (RC) structures are widely used in modern construction due to their **high strength-to-weight ratio**, efficient material utilization, and suitability for large-scale structural applications. These elements, such as shear walls, bridge piers, deep beams, and containment structures, often govern the lateral load-resisting system and are particularly critical in regions subjected to seismic and dynamic loading. However, their reduced thickness and complex stress distribution make them highly susceptible to **shear-critical failures**, which are typically brittle and sudden in nature. Understanding the behavior of shear-critical thin-walled RC structures is therefore essential for ensuring structural safety and serviceability. Unlike flexural failures, shear failures involve complex mechanisms such as diagonal cracking, aggregate interlock, dowel action, and tension softening. These nonlinear behaviors significantly influence stiffness degradation, load-carrying capacity, and overall structural performance. Conventional analytical methods often fall short in accurately capturing these intricate responses, especially under varying loading conditions.

Proposed Methodology

This algorithm works in conjunction with the *Displacement Path* Integrator (Zhong 2005) for monotonic and reversed cyclic loadings and *Newmark* integrator with *Uniform Excitation* pattern for earthquake loadings. This customised function was originally developed in MATLABTM (Mathworks 2015) & integrated with the Open SEES application. The comprehensive system for a crossing pier has been delineated in two documents in this paper: Modelfile.tcl which encompasses all simulation attributes of the bridge, including component geometry, material characteristics, or

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feedback recording, and loading.tcl, which specifies the inputs for conducting the static evaluation and the resulting inverted cyclic displaced background.

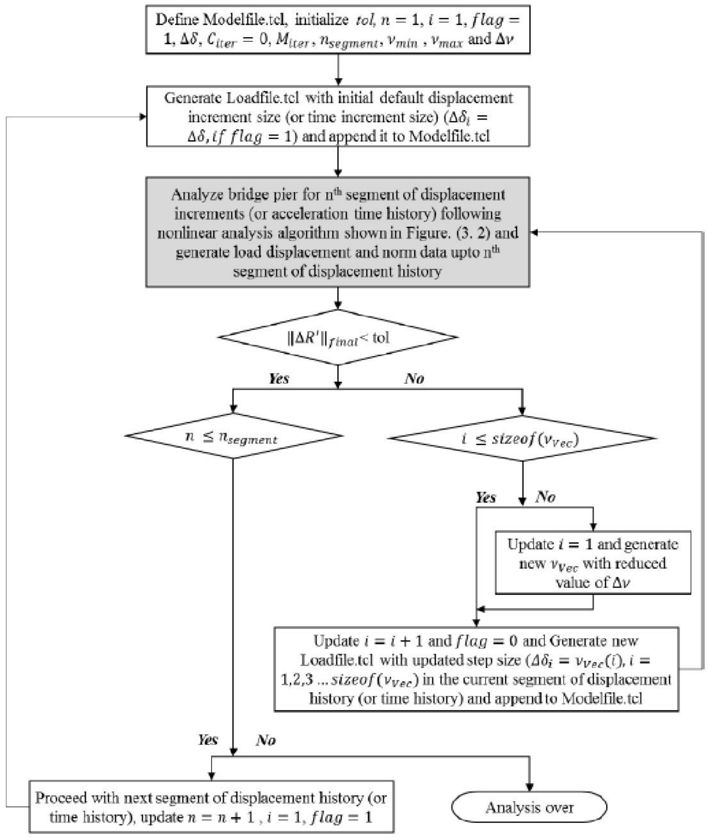

Figure 1. Mechanism for Adaptive Step Size Adjustment

II. RESULT ANALYSIS

However, the CSMM based model is very sensitive to the tolerance value and step sizes specified in the nonlinear finite element algorithm. Lower tolerance value generally results in accurate results. However, the existing CSMM results in convergence problems at higher drift levels under such strict lower tolerances. Hence, higher tolerance values have been used due to which, though the load displacement values of piers PS1 and PI2 as predicted by the existing CSMM are matching well with the experimental results, the peak force values in the first quadrant of pier PI1 are lower compared to experimental results. The shear characteristics stiffness degradation observed in the bridging piers PI1 & PI2 are also well captured. This validated model has also been used to conduct earthquake investigation of the cross pillars and the results obtained from the analysis has been presented in next section.

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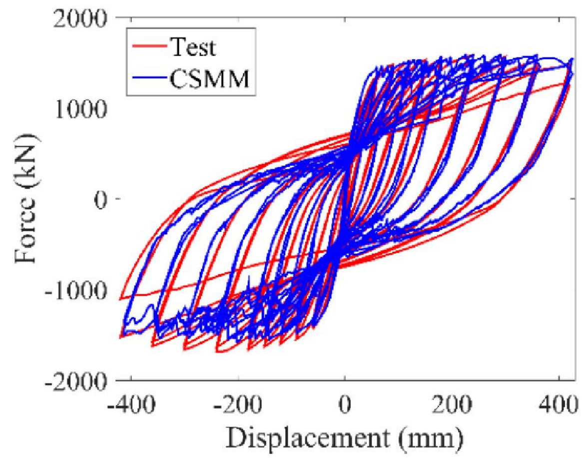

Figure 2. Loading vs Deflecting Curves of PS1 from CSMM Analysis

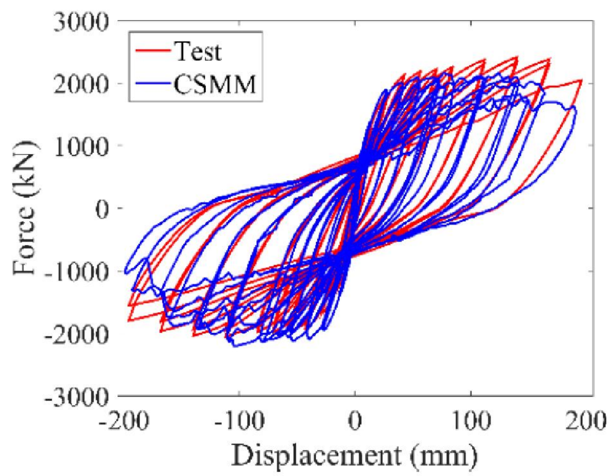

Figure 3. Loading vs Deflecting Curves of PI1 from CSMM Analysis

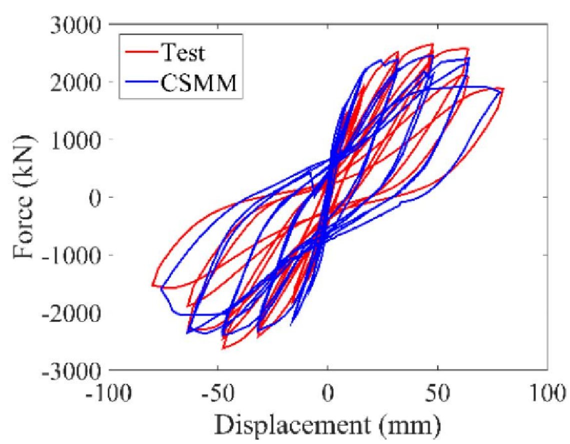

Figure 4. Loading vs Deflecting Curves of PI2 from CSMM Analysis

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III. CONCLUSION

The nonlinear finite element analysis technique was subsequently enhanced to address resolution concerns during inverted cyclical loading by integrating an user-specified function that may flexibly modify the relocation increments (or time step) in both quasi-static and transient analysis until the desired convergence is achieved. The results obtained from the analysis has been presented and discussed in detail. The hysteretic loops obtained from the analysis corroborated well with the test data. The earthquake study findings indicate that the CSMM system well predicts the earthquake reaction of the elevated bridge pillars during low PGA soil movement.

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