# *Model Analysis of Structures*

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***Abstract***

*Model analysis of structures has long been recognized as a valuable supplement to the usual theoretical methods of structural analysis and design. Its importance is now further enhanced because more of the unconventional types of structures with respect to geometrical configuration, loading pattern, and material characteristics are being constructed. Even when theoretical methods are possible, the design and construction of really large and important structures often need confirmation by independent model studies. Sometimes model analysis offers advantageous shortcuts to theoretical methods and also helps in the investigation of structural failures. Besides, most of the advanced theoretical methods of analysis, when first developed, require confirmation by suitable model studies. A vast array of well-developed instrument systems with a high degree of accuracy and reliability are also available. Today, many branches of engineering accept model analysis as an important and indispensable tool in education, research, development, design and construction. The various modeling techniques used in analyzing structural elements are explained in this paper.*

***Keywords***: *-Physical model, Analytical model, Finite element model, Lattice Discrete Particle Model, Material model*

## INTRODUCTION

Structural models have always played a significant role in structural design and research. The use of small-scale models by engineers and builders dates back to hundreds of years. However, these early models were primarily aids for planning and constructing structures and were not useful for predicting deformations and strengths of a prototype. Most models used to predict structural behaviour require measurement of strain, displacement and forces. Thus the development of modeling as a practical tool has been sharply influenced by abilities in experimental stress analysis.

A structural model is any structural element or assembly of structural elements built to a reduced scale that is to be tested and for which laws of similitude must be employed to interpret results. Structural modeling is a tool to establish three mathematical models- a structural model consisting of three basic components: structural members or components, joints (nodes, connecting edges or surfaces), and boundary conditions (supports and foundations); a material model and a load model. The correct choice of modeling and analysis tools/methods depends upon the importance of the structure, purpose of structural analysis and required level of response accuracy.

**Objective:**

Structural models can be broadly classified into physical models and analytical models. The objective of this study is to compare the various model analysis methods used for solving structural problems and choose a suitable modeling technique for a given problem

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**Physical Model:**

Full-scale tests of structures have been very valuable in helping to understand complex behaviour including yielding, cracking, and the ultimate mode of failure. Because of the relatively large dimensions of many engineering structures, full-scale tests have been restricted to simple members and configurations. In addition, very few laboratories have the necessary facilities for testing full-size elements. Small-scale direct models have been developed as an answer to the above shortcomings of full-scale testing. Small-scale models can overcome the size problems, allow studies of larger and more complex structural configurations, and in general are less time consuming and less costly to fabricate and test. The main advantage of a physical model over an analytical model is that it portrays behaviour of a complete structure loaded to the collapse stage.

Bogdan Ros CA (2008) [1] has studied the dynamic behaviour of concrete dams by means of the physical model method to understand the failure mechanism of structures under the action of strong earthquakes. Figure 1 shows the downstream view of the prototype. A study model is designed by a physical modeling process using the dynamic modeling theory. The result is an equation system which permits the dimensioning of physical model, shown in Figure 2. After the construction and instrumentation of the scale, a structural analysis based on experimental means is performed.

Physical models can be used to simulate accurately the possible opening of joint, sliding between concrete blocks and the cracking of concrete. The design relations for both elastic and failure physical models are based on dimensional analysis and similitude relations between the physical quantities involved in the phenomenon.

***Fig 1 Downstream view of prototype***

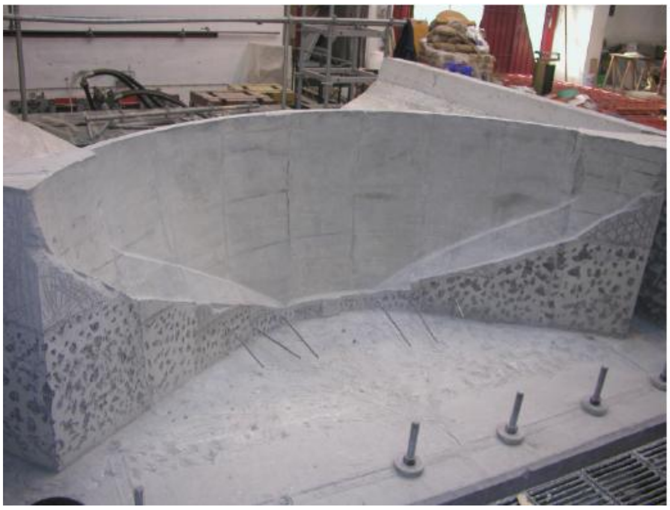
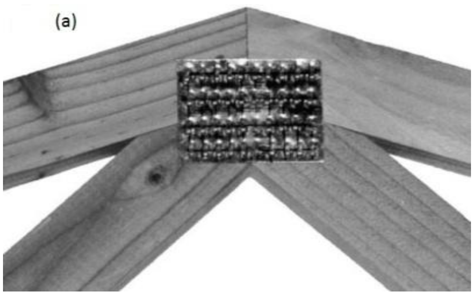
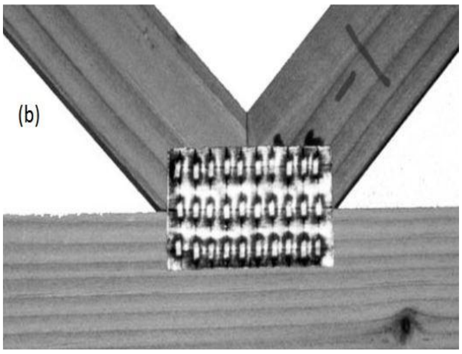


***Fig 2 Downstream view of model***

Rakesh Gupta et al., (2005) [8] developed 1/3-scale models of full-size (prototype) metal-plate-connected wood truss joints and a complete truss using similitude theory. To verify material properties, moduli of elasticity of prototype and 1/3-scale model boards were compared. Although the variation in stiffness of the model was greater than that of the prototype, the average properties of the model and prototype were similar. The resulting average design stiffness of 1/3-scale tension splice joints was within 1% of the prototype joint stiffness, while the ultimate load was 7% lower than the prototype. Stiffness and strength of model heel joints were within 22% and 17 %, respectively, of the stiffness and strength of their prototypes. Finally, ten complete model trusses were fabricated and tested; their average stiffness and strength were 780 N/mm and 17.3 kN, respectively, after scaling up by similitude. Modeling full-size truss connection behavior up to the design load, and possibly to failure, with small-scale models and similitude theory may be feasible. Figure 3 shows the truss connections.



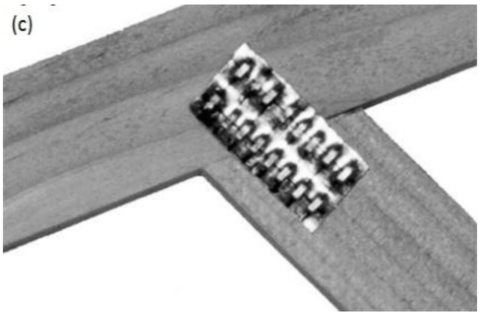




***Fig 3 Model Truss Connections: (a) Peak Joint; (b) Bottom Chord Truss Joint; (c) Top Chord Web Joint***

Magued Iskander and Jinyuan Liu (2010) [5] address the need for nonintrusively measuring spatial deformation pattern inside soils using transparent soil surrogates in model tests instead of natural soils. Transparent soil with macro-geotechnical properties similar to those of natural soils was made of either transparent amorphous silica gels or powders and a pore fluid with a matching refractive index. An optical system consisting of a laser light, a line-generator lens, a charge-coupled device camera, a frame grabber, and a computer was developed to optically slice a transparent soil model. A 3D view of image slices is shown in Figure 4. The laser speckle images before and after deformation were used to nonintrusively measure the relative displacement field using digital image cross-correlation.

**Analytical Model:**

Analytical models are mathematical models that have a closed form solution, i.e. the solution to the equations used to describe changes in a system can be expressed as a mathematical analytic function. An analytical model is a description of a system using mathematical concepts and language. A mathematical model usually describes a system by a set of variables and a set of equations that establish relationships between the variables.

Often when engineers analyze a system to be controlled or optimized, they use a mathematical model. In analysis, engineers can build a descriptive model of the system as a hypothesis of how the system could work, or try to estimate how an unforeseeable event could affect the system. The analytical models discussed here are the boundary element method, lattice discrete particle model, finite element method and finite volume method.

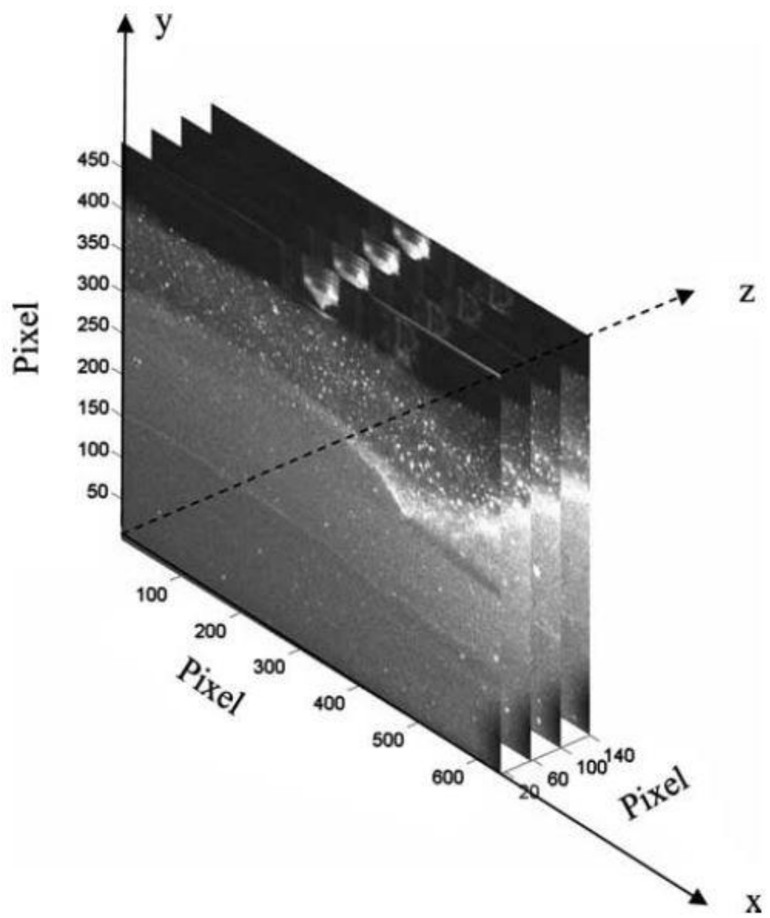



*Fig 4 3D View of Image Slices*

***Lattice Discrete Particle Model (LDPM):***

The Lattice Discrete Particle Model is a mesoscale model for heterogeneous materials. Developed for concrete, it simulates material mesostructure by modeling coarse aggregate particles and their surrounding mortar as polyhedral cells. A tetrahedralization of the particle centers generates a lattice framework where each lattice member is associated with a triangular-shaped plane of contact (facet) between two cells. Compatibility equations are formulated by describing the deformation of an assemblage of particles through rigid-body kinematics. Equilibrium equations are obtained through the force and moment equilibrium of each cell. The material behavior is assumed to be governed by a vectorial constitutive law imposed at the facets.

Edward A. Schauffert et al., (2012) [3] have developed Lattice Discrete Particle Model which simulates the material mesostructure by modeling coarse aggregate particles and their surrounding mortar as polyhedral cells. Particles with assumed spherical shape and in accordance with typical mix designs and granulometric distributions are introduced randomly into the volume through a procedure that avoids particle overlapping and ensures that all particles are contained within the volume of interest. A tetrahedralization of the particle centers generates a lattice framework where each lattice member is associated with a triangular-shaped plane of contact (facet) between two cells. Figure 5 shows two adjacent particles along with their polyhedral cells and the associated tetrahedron edge.

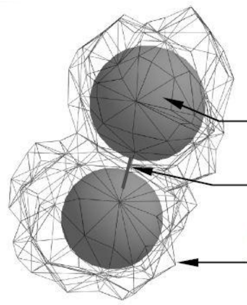



***Fig 5 Two Adjacent Particles Along With Their Polyhedral Cells***

A new computational framework for the simulation of Fibre Reinforced Concrete (FRC) has been formulated. The new formulation is based on a two-scale analysis in which the fine-scale fiber-matrix interaction problem is solved independently and the overall response is used in a 3D mesoscale analysis based on the formulated LDPM. The LDPM describes mesostructure deformation through the adoption of rigid-body kinematics. Based on this assumption, and for given displacements and rotations of the particles associated with a given facet, the relative displacement at the centroid of the facet can be used to define the strain.

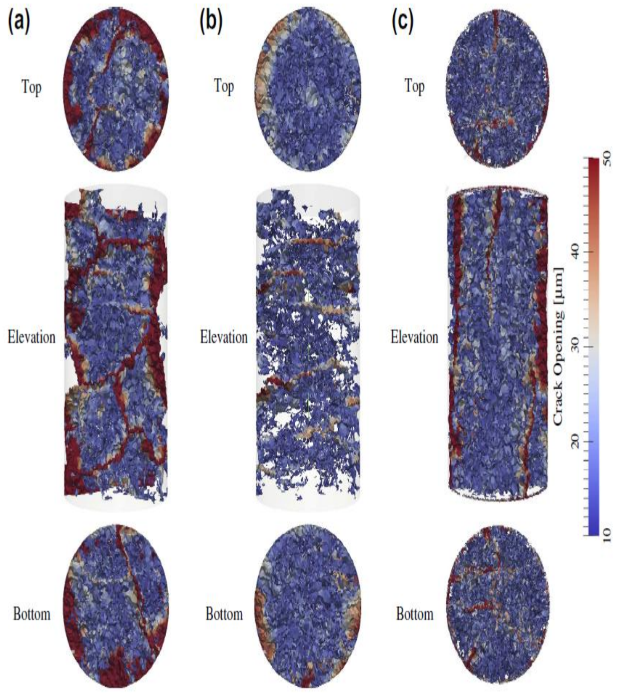



***Fig 6 Crack Patterns Simulated In One Specimen For (a) Free Expansion Case, (b) 0 Mpa And 5-Mm-Restraint Case And (c) 20 Mpa Unrestrained Case***

Mohammed Alnaggar et al., (2013) [6] present the formulation of Lattice Discrete Particle Modeling of Alkali Silica Reaction (ASR), to simulate the effect of ASR on concrete structures. ASR-LDPM implements, within the mesoscale framework of LDPM, a model describing ASR gel formation and expansion at the level of each individual aggregate particle. The common disadvantage of other models is the inability to simulate crack patterns and crack distribution due to ASR. This, in turn, limits the ability to predict the degradation effect of ASR and forces the assumption of phenomenological relationships between ASR gel expansion and concrete mechanical properties. In addition, it also limits the ability of such models to explain complex triaxial behavior of concrete under ASR. These limitations are inherently connected to modeling concrete as an isotropic and homogenous continuum.

Figure 6 shows the random and heterogeneous nature of crack patterns in simulated specimens subjected to ASR. The cracks shown represent cracks with openings larger 10 μm. Figure 6(a) shows the crack pattern distribution of one simulated specimen under unrestrained free expansion. Figure 6(b) shows the calculated crack pattern for the case of passive restraining with 5-mm restraint under no axial loading. Opposite situation arises if, again, the same specimen is subjected to axial load and without restraint as shown in Figure 6(c) for the 20 MPa case.

***Finite Element Model:***

Hui Zhang et al., (2010) [4] have proposed a new type of streamlined girder (lenticular cross-section) bridge with a thin-walled steel box girder. In order to deal with the problem of increasing traffic congestion, this bridge is designed with a large width-to-span ratio, which results in significant shear lag effects and causes non-uniform stress distribution in the three-cell thin-walled box girder, especially along the flanges of the girder. The aim of this study is to investigate the effect of shear lag in thin-walled box girder bridges with large width to span ratios through both experimental and numerical studies. A large-scale Plexiglas model as shown in Figure 7 is tested under different loading cases.

The material parameters are obtained from physical characteristics tests and tensile tests. In addition, a computational model is presented for a comprehensive simulation of a girder bridge including the orthotropic top, bottom, web plates and their ribs, which leads to accurate modeling of structural properties of the girder. The simulation of the computation results compared well with the experimental results. It is illustrated that the finite element analysis is an effective method to predict properties of this class of bridges. The FE model for the steel box girder (Figure 8), in which a fully precise and detailed model of all the components is established, is built by using shell elements.

***Fig 7 Plexi- Glass Model***

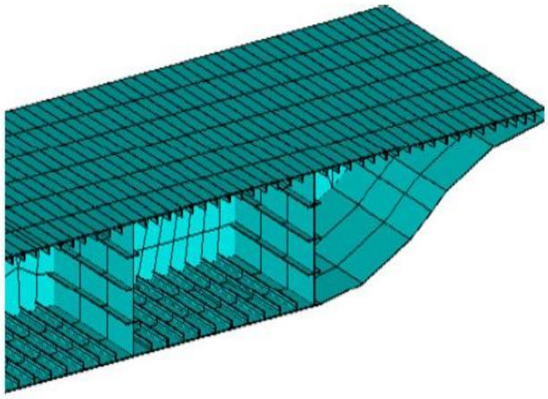


***Fig 8 Finite Element Model***

Rami A. Hawileh et al., (2013) [9] have numerically investigated the plate debonding and performance of reinforced concrete (RC) beams externally strengthened with bonded Carbon Fiber Reinforced Polymers (CFRPs) plates running for a length covering 25% of the shear span. The results are compared with plates covering 85% of the shear span in addition to a control unstrengthened specimen. The aim of this paper is to develop 3D finite element (FE) models that can accurately simulate the response and performance of RC beams externally strengthened with short-length CFRP plates. Figures 9 and 10 show a comparison between the simulated and experimental failure modes of the tested beam specimens.

Dalalbashi A. et al., (2013) [2] presents a numerical investigation into the effectiveness of carbon fiber–reinforced polymer (CFRP) sheets in enhancing the seismic performance of RC joints under combined axial and cyclic loads. For this purpose, a case-study joint sub - assemblage was retrofitted using three different retrofitting configurations (L-shaped, web bonded, and flange bonded).

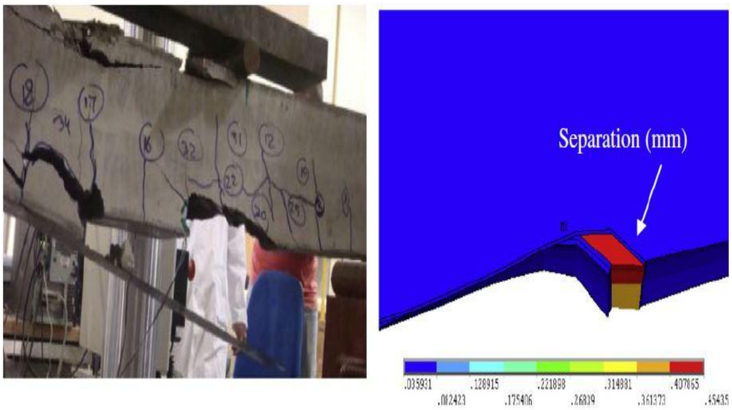



*Fig 9 Simulated and Experimental Results of CFRP Plate De-Bonding*

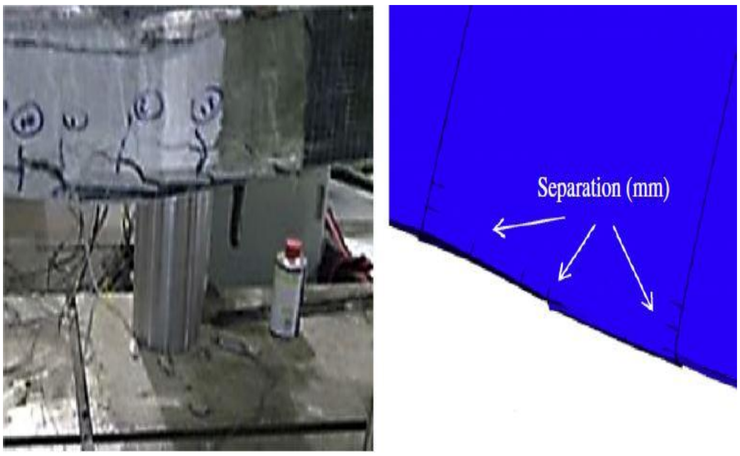



*Fig 10 Simulated And Experimental Results Of Cover Delamination*

Following the verification of the nonlinear numerical model against the existing experimental data, the analysis outcomes of the retrofitted specimens were compared with those of the control specimen in terms of the tip beam load distribution versus tip beam displacement, energy dissipation, and plastic hinge relocation. Compared with the results of the original joint, the results of the retrofitted joints confirmed an improved load-carrying capacity for all strengthening schemes.

The numerical modeling performed in this study on the original and retrofitted joints confirmed that finite element modeling can adequately simulate the cyclic behavior of RC joints, especially in terms of load carrying capacity. Figure 11 shows the finite element model of the beam column joint.

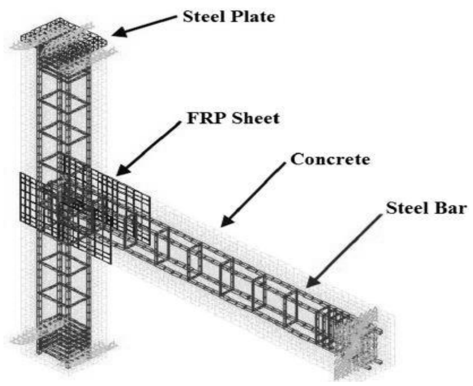



***Fig. 11 Finite-element illustration of retrofitted specimen***

## CONCLUSION

A detailed review of the literature shows that the most widespread approach for analytical modeling is the finite element method. FEM, validated by means of numerical/experimental comparisons, can be an effective tool to better understand the basic damage mechanisms, and to evaluate the stress and strain state in the constituent materials and structural elements.

It can be concluded that –

- Full-scale tests of structures have been very valuable in helping to understand complex behavior including yielding, cracking, and the ultimate mode of failure.
- The main advantage of a physical model over an analytical model is that it portrays the behaviour of a complete structure loaded to the collapse stage.
- Small-scale models allow studies of larger and more complex structural configurations, and are less time consuming and less costly to fabricate and test.

- Finite element model can be used for composite and multiphase materials. In the last two decades research activities have been directed towards the development of advanced models for the numerical simulation of crack propagation, multi-phase models considering concrete as a porous material. Finite element model can be easily refined for improved accuracy by varying element size and type.

- Once a comprehensive CAD model is developed, application of FEM can analyze the design with details and thus saves time and investment reducing the requirement of making expensive prototypes. In case an existing product needs to be improved, FEM can be used to modify and analyse in a cost effective price.

- The disadvantage of finite element models is that the model needs to be refined repeatedly to assure that the results are reasonably accurate.

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