COMPUTER AIDED ANALYSIS, DESIGN AND OPTIMIZATION OF MULTISTORIED BUILDING SUBJECTED TO SEISMIC AND WIND LOADING

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ABSTRACT

An economical structural system which would mitigate undesirable cost due to seismic and wind loads.Seismic and wind loading should consider carefully in Building design in Bangladesh which is situated highly earthquake and tornedo/tyfoon pron area. The objective of this research is to analysis, design and optimization of multistoried building subjected to seismic and wind loading using ETABS and OPTIMA software respectively. Two case study of computer aided analysis, design and optimization of multi-storied building subjected to seismic and wind loading have been conducted in this research. The base shear, seismic load of different floor level and seismic shear of different floor level are calculated in this study. An extensive analysis and design works was conducted on column axial load, column-beam shear & moment for eight storied residential building considering combination of dead load, live load and earthquake load according to BNBC-2013. The deflection of various members, inter-storey drift, lateral displacement of the whole structure and stress of all members were checked comparison with limiting value of the design criteria. Moreover, a research is conducted on 67 storied tall building to determine the size and stiffness of the variable structural elements due to the lateral combined wind load resisting system. After the preliminary design, the various cross section of beams and column were reduced by considering their efficiency. Finalize the optimum member sizes in which the volume of concrete and quantity of steel is saved to precise amount and maximize the usable floor area by satisfying the design criteria. Finally, the optimum member sizes increase the floor area and saving cost up to 12.24% and 10-30% for seismic and wind loading respectively.

Keywords: Building; computer aided analysis; design and optimization; siesmic and wind loading

INTRODUCTION

Structural engineers are facing the challenge of striving for the most efficient and economical design solution while ensuring that the final design of a building must be serviceable for its intended function, habitable for its occupants and safe over its design life-time. Generally, the design of buildings must satisfy earthquakes or severe wind storm loading criteria. The building should have sufficient strength and stiffness to control deflection and prevent any structural damage or collapse. Deflection of various members, inter-storey drift and lateral drift performance is a principal concern in the seismic design of building structures. The economic design of elements of building structures for various levels of lateral drift performance under multiple levels of earthquake loads is generally a rather difficult and challenging task. Chan and Zou (2004) conducted a research on drift performance optimization for reinforced concrete buildings under earthquake loads using optimality criteria approach. An efficient computer-based optimization technique has been developed for lateral stiffness design of tall buildings by Chan (1997), Chan and Sui (1997). They developed an efficient computer-based optimization technique for lateral stiffness design of tall buildings. The optimization technique, based on a rigorously derived Optimality Criteria (OC) approach, is capable of optimizing large-scale tall steel and or reinforced concrete buildings subject to multiple static wind drift and dynamic wind-induced vibration design constraints.

The effectiveness of the state-of-the-art optimization technique has been demonstrated through its actual design application on a number of the tallest buildings in Hong Kong Chan (2001, 2004). Field application projects optimized by OPTIMA softwere is shown in Fig. 1. Chan (2004). These actual applications represent a major advance in the use of structural optimization techniques for practical tall building designs, it should be noted that the research has been primarily focused on the elastic wind drift performance of tall buildings. ETABS soft were used for optimization of selected field applied projects as shown in Fig. 2. Much effort is still needed to extend the current optimization technique to inelastic seismic design of multi-story buildings. Recent trends to construct increasingly slender and taller buildings which are wind-sensitive. Very often, such slender and tall buildings different member size and stiffness may experience over design or under design. Optimization technique can overcome this problem. Therefore a research is needed for effective analysis, design and optimization technique of multistoried building. Selected Building This paper presents an effective analysis, design and optimization technique of multistoried building subjected to seismic and wind loading using ETABS and OPTIMA. Optimization technique always improves the quality of design, increase the floor area and saving cost.

Fig. 1: Selected building projects optimized by OPTIMA in Hong Kong, China

Fig. 2: Selected building projects optimized by ETABS in Rajshahi, Bangladesh

METHODOLOGY

The emerging structural optimization technology provides a promising design tool to automate the structural synthesis process and to aid in searching for the best design to meet various design requirements.Transforming structural optimization theory into design practice of realistic civil engineering structures has always been regarded a difficult task An extensive reserach to analysis, design and optimization of multi storied building is conducted subjected to seismic and wind loading using ETABS and OPTIMA software respectively. A eight story residential buliding is considered for analysis, design and optimization subjected to sismic loading using ETABS. Although there exist powerful finite element software for precise prediction of dynamic seismic responses of structures, structural optimization of large-scale building structures for various levels of elastic and inelastic seismic performance under multiple levels of earthquake events is generally a challenging and difficult task.

Recent attempts have been made to develop an automatic optimal elastic and inelastic seismic drift design of concrete framework structures Chan and Zou (2004), Zou and Chan (2004, 2005a) and base-isolated building systems Chan (2005b). Research in the past normally expressed dynamic response performance constraints by calculating sensitivity derivatives of equations of motion with respect to design variables. Such a sensitivity formulation may be straightforward; but it requires enormous instantaneous sensitivity computations and may lead to divergent solution fluctuations. The recent studies have shown that a more stable seismic drift responses modeled by various response spectrum, time history and pushover analysis methods can be formulated accurately by the Principle of Virtual Work Chan and Zou (2004), Zou and Chan (2004, 2005a). Once the structural form of a building is established, the major effort is to size the structural members to satisfy all safety and wind-induced stability and serviceability design requirements. For a general tall building structure composed of $t_s = 1,2,..,\ N_s$ skeletal steel, $i_c = 1,2,..,N_c$ concrete frame elements and $i_t = 1,2,..,\ N_t$ concrete shear wall panels, the optimal element sizing design can be formulated as follows.

$$\text{Minimize Cost}(A_{i_s}, B_{i_c}, D_{i_c}, t_{i_w}) = \sum_{i_s=1}^{N_s} w_{i_s} A_{i_s} + \sum_{i_c=1}^{N_c} w_{i_c} B_{i_c} D_{i_c} + \sum_{i_w=1}^{N_w} w_{i_w} t_{i_w} \qquad (1)$$

This formulation was considered subject to top drift constraints, inter storey drift constraints, wind induced acceleration constraints, element strength constraints, steel element, sizing constraints, concrete element width sizing, constraints, and concrete element depth sizing constraints, concrete wall thickness sizing constraints. Similarly, a sixty five story tall buliding is considered for optimization subjected to wind tunnel loading using OPTIMA software. Building model was generated, assign load, analysis, design and optimization have been completed according to the requirements of the selected building code. OPTIMA has been based on an integrated system approach as outlined in Fi

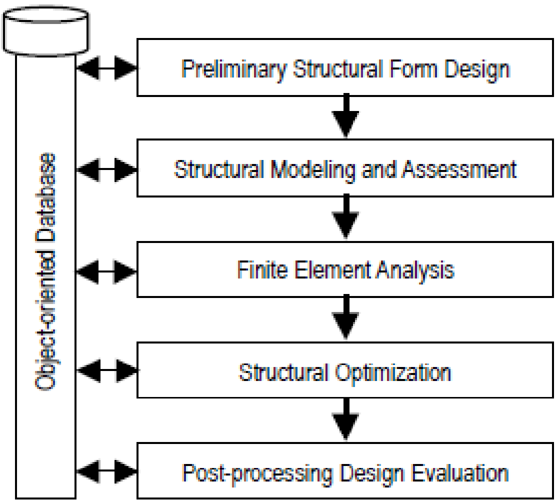
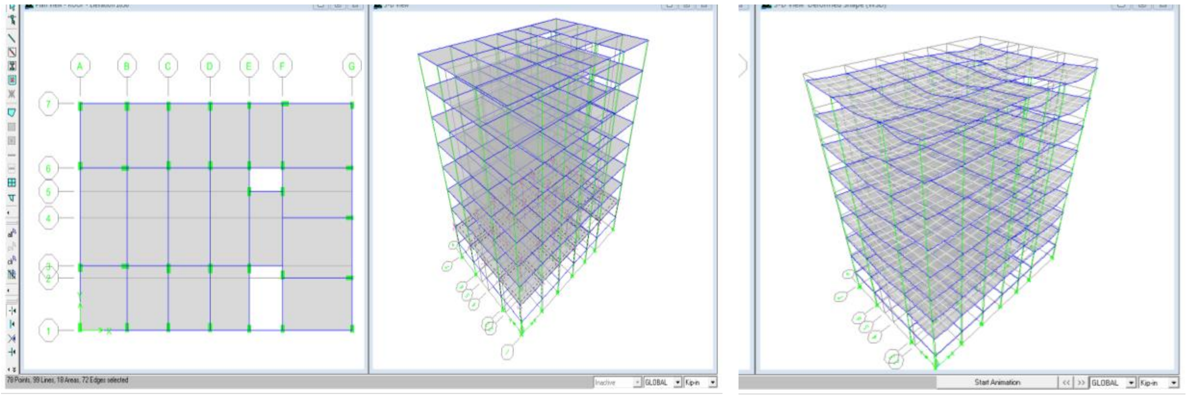


Fig. 3: Integrated design work flow

Optimal design formulation is included in this study. All of these modeling and analysis options are completely integrated with a wide range of steel and concrete design features. In this paper, the Optimality Criteria (OC) method, which has been widely used in the aerospace industry Venkayya (1989) and shown to be very effective in lateral drift design of tall buildings Chan (1992, 1997, 2001) and Chan et al (1995) will be extended to minimize the cost of tall symmetric steel buildings subject to wind-induced acceleration performance constraints expressed in terms of the natural frequency of the building. In this approach, a set of necessary optimality conditions for the optimal design is first derived and a recursive algorithm is then applied to search for the optimal design indirectly by satisfying the set of optimality conditions.

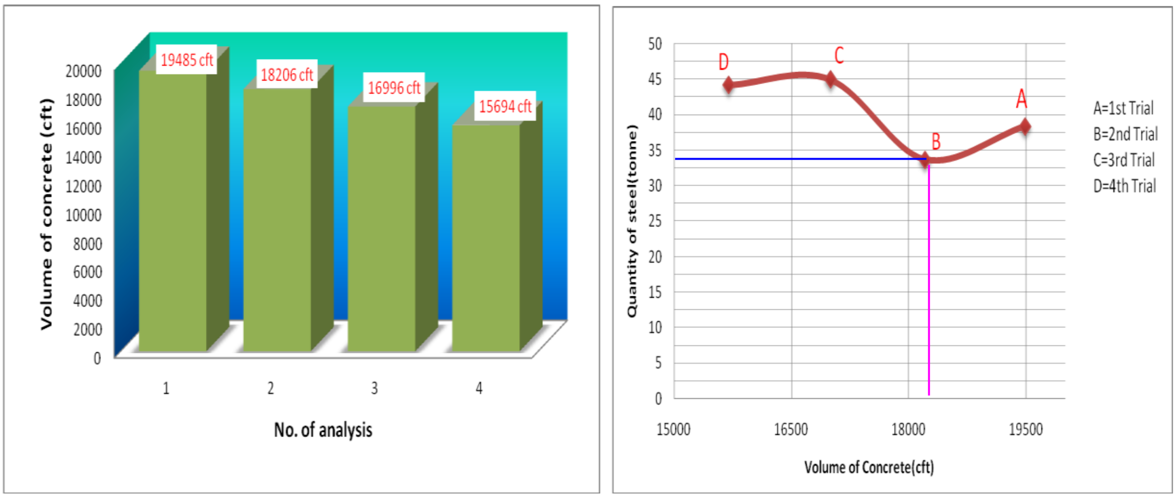
RESULTS AND DISCUSSIONS

Building model and deflected shape of the building by ETAB‘S subjected to earthquake load is shown in Fig. 4. Fig 5 presents the variation of quantity of concrete vs No. of trial analysis and quantity of steel vs volume of concrete. Optimum point was found at point B. Optimal structure design is becoming increasing significant due to limited material resources. Fig. 6-7 presents the optimal design modling and results form numerical analysis. The members which is shown red colour in the work density diagram shown are considered as the relative efficient members (or the critical members) of the structure under the given set of design constraints as shown in Fig. 5 and 6. In this model, the efficient members under the given set of wind load are found. Economy in design can be achieved through an optimization procedure by aiming to find the most efficient structure that will satisfy the design criteria.



(a) Generation of the building model (b) Deflected Shape of the structure

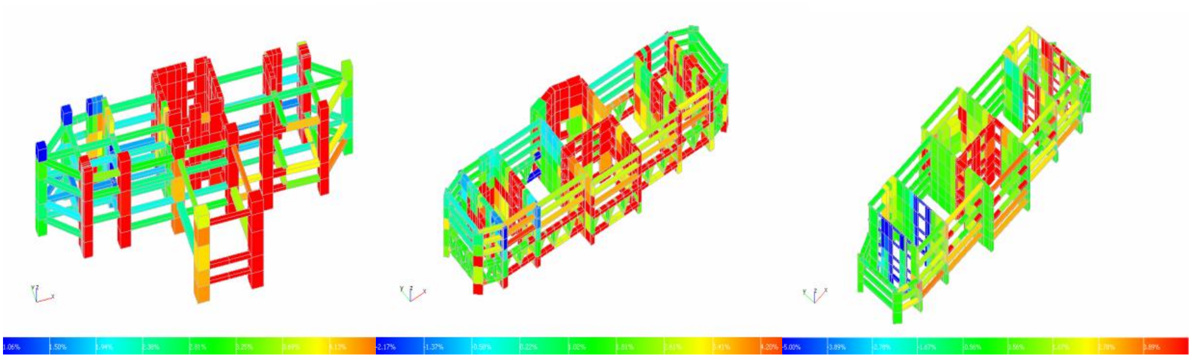
Fig.4: Generation of building and deflected shape of the building by ETAB‘S



(a) Variation of concrete – No. of trial analysis. (b) Variation of quantity of steel vs volume of concrete

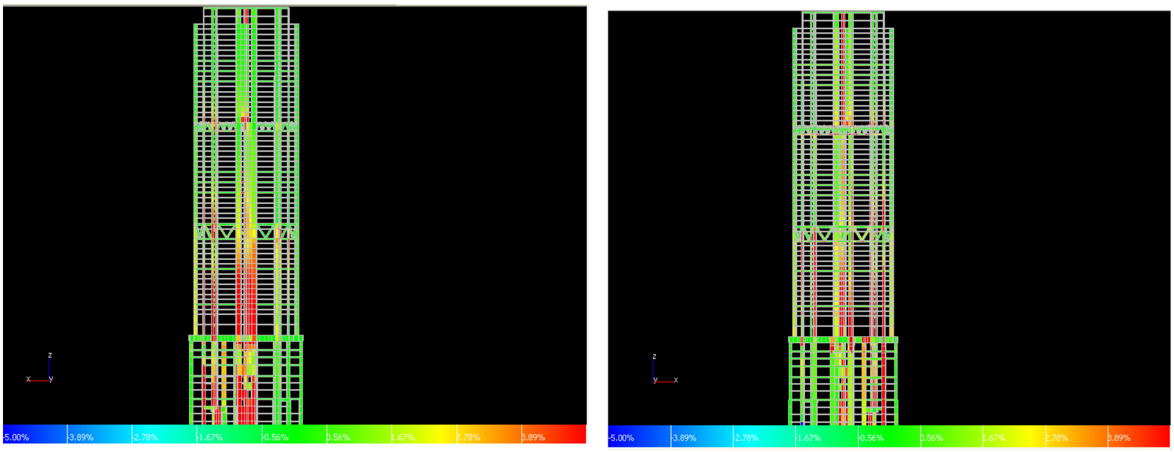
Fig. 5: Variation of quantity of concrete vs No. of trial analysis and quantity of steel vs volume of concrete

The cost comparison of initial model of 67 storied tall build subjected to wind loading and optimized model is shown Table 1. The optimum member sizes increase the floor area and saving cost up to 12.24% and 10-30% for seismic and wind loading respectively.



(a) Work density of 6-10 floor (b) Work density of 51-55 floor (c) Work density of 68-73 floor

Fig. 6: Work density of different floor using OPTIMA



(a) Front view (b) back side view

Fig 7: Over all work density of Front view and back side view.

Table 1. Initial and optimized model comparison using OPTIMA

Item	Initial design Model	5th Cycle optimized design model
Drift (Overall)	1 / 424.52	1 / 424.52
Total Column Member (No.)	380	380
Total Beam Member (No.)	2,897	2,905
Total Wall (No.)	7,357	7,358
Brace (No.)	94	102
Total Structure Element (No.)	10,728	10,744
Total length of element	11,414	11,520
Total planar area (m^2)	1,704	1,810
Total volume of element (m^3)	14,157	13,850
Total cost ($)	4.59 x 10^7	(Approx.) 4.11 x 10^7
Cost Saving		= 0.48 x 10^7

CONCLUSIONS

Structural optimization is an advanced computational technique, which replaces the traditional trial-and-error design procedure by a systematic goal-oriented design synthesis process. Remarkable progress has been made on developing an optimization procedure for element sizing optimization of practical tall buildings. The effectiveness of the state-of-the-art optimization software OPTIMA has been well attested through applications to the design of numerous tallest building projects in Hong Kong and Bangladesh. While some initial successes in practical structural optimization have been demonstrated in the lateral stiffness and serviceability design of tall buildings, research is still needed to advance the field of structural optimization to further develop innovative techniques for a wider spectrum of design problems associated with practical engineering of buildings. The efficient members under the given set of wind load are found. Economy in design can be achieved through an optimization procedure by aiming to find the most efficient structure that will satisfy the design criteria. The optimum member sizes increase the floor area and saving cost up to 12.24% and 10-30% for seismic and wind loading respectively. Efficient structural design also leads to a better foundation design, even in difficult soil conditions.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Hong Kong University of Science and Technology, Hong Kong, China and Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh

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