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Optimum Design of Steel Moment Resisting Frames Subjected to Seismic Excitation

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Abstract: The main aim of this project is to develop an interior penalty function (IPF) based algorithm to multi-storey steel frames for minimum weight of frames. The frames are intended for resisting lateral sway due to seismic loading along with gravity forces. Many structural systems are used for resisting seismic (lateral) forces; however steel moment resisting frames (MRF) are considered for the present work. The design methodology incorporates codal provisions of IS 800-2007, thereby obtains the frames with optimum weight for in-plane moments with lateral support of beam elements. Strength and buckling criteria are considered as behaviour constraints along with side constraints in formulating optimization problem. A computer program is developed that uses an interior penalty function (IPF) for weight minimization of two-dimensional moment resisting steel framed structures. The program uses MATLAB, performs one dimensional search, and structural design in an iterative procedure. The design examples have shown that the proposed algorithm provides an efficient tool for the practicing structural engineers. The program is applied to 6 and 9 storey (4 bays) moment resisting frames (MRFs). The program demonstrated its capability of optimizing the weight of two medium size frames. To obtain member forces in frames an analysis procedure has to be applied.
In the present work Equivalent Lateral Force procedure (ELF) and material nonlinear time history analysis (NTH) are applied and optimum values obtained from both the analyses are compared.

Keywords: Text detection, Inpainting, Morphological operations, Connected component labelling.

I. INTRODUCTION

Design of steel structures for seismic loads generally allows for structural damage during severe seismic events. The distinctive design objective is to limit material yielding to specific zone and to provide enough ductility in the system to prevent collapse of the structures under seismic loads. Such a design is achieved through moment resisting frames. Another design objective is to obtaining cost advantage, which is to be achieved by using appropriate optimization technique. In this study a new optimization technique is developed as per Indian code for design of steel structures incorporating with interior penalty function method. This technique is applied to steel building lateral force resisting frames; that is rigid beam-column connected frame system, called Moment Resisting Frames (MRF).A proper structural analysis procedure has to be selected to obtain design forces in structural elements of frames under consideration. American Society of Civil Engineering (ASCE 7-10) requires the proper structural analysis method is selected from different procedures. The present work uses Equivalent Lateral Force (ELF) Procedure to analyse frames under consideration.Tremblay et al. (2006). This symmetric hysteretic behaviour provides improved ductility over traditional braces and moment resisting frames (MRFs) which are limited by poor post-buckling resistance to compressive loads.

The present work develops a new optimization technique considering post-buckling yield strength of material. The developed technique is applied to moment resisting frames (MRFs). These are conventional vertical frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components (that are more rigid and will prevent the frames from deflection) when subjected to seismic forces.

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II. LITERATURE REVIEW

Considerable research has been conducted on the behaviour of steel moment resisting frames (MRF) and optimization techniques for minimum weight design under seismic ground excitation. Because of the rapid evolution of codes, much of this research is not necessarily consistent with modern construction detailing; however, many of the fundamental observations from these investigations are relevant to an assessment of modern design and analysis procedures. The available collection of literature extends over several decades and is rapidly growing. As such, it cannot adequately be summarized in a brief chapter. Instead, an overview of major references is provided here along with useful citations to previous works that contain detailed reviews of related literature.

The literature review in this chapter is separated below into two categories:

(i) Optimization of steel frames, which examines references that describe the optimum design of framed/braced steel structures of recent earthquakes in the United States, Mexico, Japan and India.

(ii) Moment resisting frames, which discusses the previous experimental and analytical works on moment resisting braced frames relevant to seismic applications.

Considerable literature also exists on numerical modeling of buckling restrained braces, anticipation of performance and behavior of various configurations of braced-frame/framed systems, and sensitivity of behavior to various ground motion and structural characteristics. This literature will not be reviewed in this chapter, but rather distributed throughout the remainder of the report where these particular topics are considered.

III. ANALYSIS PROCEDURE

The job of a structural engineer is to ensure that the buildings modelled are built to withstand the tests of time and nature. And because of such, it has been proven necessary to apply a number of analysis techniques in building designs. Such two techniques presented in this work are time history analysis, a performance based analysis technique, and ASCE 7-10's Equivalent Lateral Force (ELF) procedure. The latter is a procedure that is analysed to mimic real loads caused by earthquakes, while the former is meant to test the building performance against an actual earthquake excitation. Six and nine-storey steel building frames were analysed according to both analysis procedures. The goal is to determine which method of analysis will produce the best results with the most minimal analysis specifications.

Typically, seismic loads are resisted by axial member forces in the bracings, gravity forces (dead loads and imposed loads) and partly seismic forces are resisted by beam shear forces and bending moments and column moments and compressive forces. To determine member forces and displacements SAP2000 Version 11 is used. In this analysis beam-column connections are assumed to be fully restrained and geometrical nonlinearity in the frames is ignored by considering bi-linear material nonlinearity as shown in Figure 3.1.

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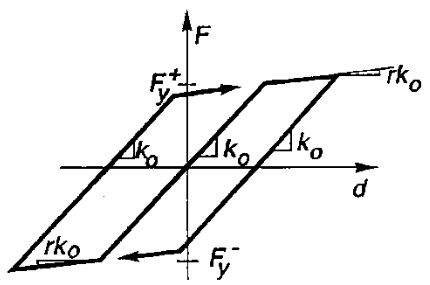

Figure 3.1 The simplest hysteretic model with no stiffness shown after yielding.

The design of MRFs is governed by Indian building code and recommended provisions are available in literature. Structural Engineers Association of California (SEAOC) group in association with various research agencies developed the recommendations.

The design dead and live loads of 9.87 kN/m and 13.77 kN/m respectively were used for analysis and design of above referred frames. The damping ratio for dynamic analysis was assumed to be 5% of the critical damping. The importance factor of 1.0 and zone factor 0.36 was used to obtain design base shear. The beams and columns were designed as per IS: 800-2007 and seismic provisions of IS: 1893 (Part-1)-2002. The MRFs were designed as per FEMA-450, in which the response modification factor 5 for MRFs. The yield stress of the structural steel was taken as 250MPa.

The considered model building frames details are given in table 3.1 and elevations are shown in Figures 3.2.1- 3.2.2.

Table 3.1 Steel Model Building Frame Details.

Model Building Frame	No. of Storeys	Storey Height (m)	No. of Bays	Bay Width (m)	Total Frame Height(m)
MRF6	6	3.000	4	7.000	18.000
MRF9	9	3.000	4	7.000	27.000

Note: MRF6=six-storey moment resisting frame; 4^{th} digit indicates number of storeys.

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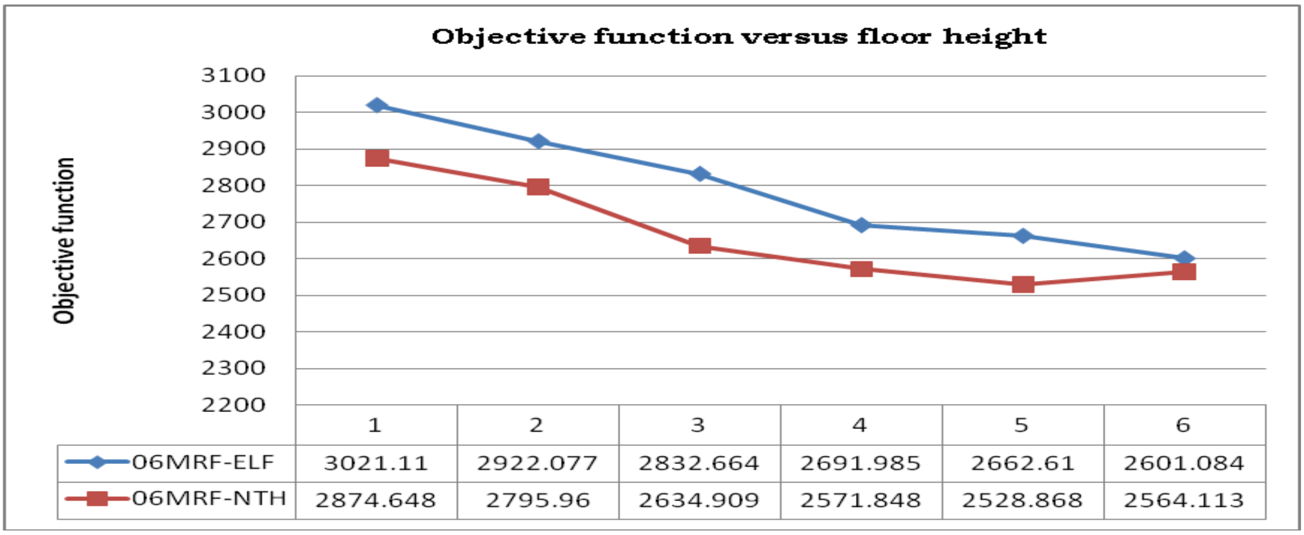
IV. EXPERIMENTAL RESULTS

Design Variables and Objective Function Values for Six Storey MRF using ELF Procedure

Floor - 6 (Roof)					
Column No	Design variables				Ø-Values
	x1 (mm)	x2 (mm)	x3(mm)	x4 (mm)	(kg)
6	10.685	179.512	10.258	430.830	195.659
12	6.000	91.555	6.000	219.731	57.284
18	6.000	65.778	6.000	157.867	41.156
24	6.000	72.522	6.000	174.053	45.376
30	10.774	180.996	10.343	434.391	198.907
				Total (kg)	538.382
Beam No					
36	11.855	222.867	10.613	445.733	553.798
42	11.650	219.023	10.430	438.046	534.861
48	11.493	216.075	10.289	432.150	520.558
54	10.727	201.675	9.604	403.349	453.486
				Total (kg)	2062.702
				Total Floor Weight (kg)	**2601.084**



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V. CONCLUSION

From the results obtained from the newly developed algorithm using interior penalty function method the following conclusions can be drawn;

ELF procedure is more conservative in comparison with Non-Linear Time History (NTH) analysis for the steel Moment Resisting Frames (MRFs) subjected to seismic loading along with gravity forces.

In multi storey steel frames the cost function decreases with the increase of floor height for low rise frames. For medium rise frames it decrease in moderate.

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