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APPLICATION OF CONSTRAIN CONTROL METHOD OF OPTIMIZATION IN SEISMIC DESIGN OF STEEL FRAMES

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In performance-based seismic design of structures, the main objective is to design the structure such that its performance is predictable under certain risk levels. In PBD, in addition to strength, other seismic performance parameters, such as ductility, stiffness and drift have a profound effect on the performance of the structure. In order to predict the performance of a structure (or structural component) subjected to a certain demand earthquake, its capacity curve should first be established. There are different methods of determining the capacity curve of a system, including: nonlinear static (pushover), cyclic or time-history dynamic loading analyses. The pushover analysis method is a practical method, which while being relatively simple, reasonably accurately estimates the seismic performance parameters of the structure and its components, such as ductility, behavior factor and toughness and can easily be utilized in optimization algorithms.

Optimization problems are generally solved subject to certain constraints. The optimum answer to a system takes place when these constraints are used to the maximum and the variables which maximize the value of all constraints are the optimized answer. An optimization method is developed, based on conventional engineering design philosophy, whereby optimum design is achieved gradually by controlling the problem constraints (Mansouri & Maheri, 2019). In the developed method, termed ‘Constraint Control Method’ (CCM), by considering the ratio of any constraint value to its limit value, the constraints are transformed into coefficients ranging from 0 to 1. They are, therefore, dimensionless so that they could be compared with each other and the constraint value is significant; that is, when the value of the constraint is zero, the answer is far from the optimum answer and the constraint value of one is the maximum value which a constraint could reach.

In this study, two sets of constraints are defined for the CCM. The first set, (CR_s) includes the stress constraints for members undergoing axial force and bending moments due to gravity loads, based on the AISC-LRFD specifications (AISC, 2001) and specified according to Equation 1.

$$\begin{cases} CR_s = \left(\dfrac{P_u}{\varnothing .P_n}\right)_i + \dfrac{8}{9}\left(\dfrac{M_{ux}}{\varnothing_b M_{nx}} + \dfrac{M_{uy}}{\varnothing_b M_{ny}}\right) \le 1 \quad \text{If} \quad \left(\dfrac{P_u}{\varnothing .P_n}\right)_i \ge 0.2 \\ CR_s = \left(\dfrac{P_u}{\varnothing .P_n}\right)_i + \left(\dfrac{M_{ux}}{\varnothing_b M_{nx}} + \dfrac{M_{uy}}{\varnothing_b M_{ny}}\right) \le 1 \quad \text{if} \left(\dfrac{P_u}{\varnothing .P_n}\right)_i < 0.2 \end{cases} \tag{1}$$

In Equation 1, P_u is the required axial force and P_n is the nominal axial capacity. Besides, M_{nx} and M_{ny} are nominal bending capacity in x and y directions, M_{uy}, M_{ux} are factored bending moment in x and y directions, $\varnothing_b$ is bending strength reduction factor and $\varnothing$ is axial strength reduction factor.

The second set of constraints (CR_d) are related to the lateral seismic loading in the form of relative lateral storey displacements (relative drift) at different OP, IO, LS and CP performance levels. In order to calculate the relative drift, the pushover capacity curve for the frame, corresponding to the roof level is evaluated and used to estimate the storey relative drift (storey = 1, 2, …, *ns*) for different performance levels (*i* = OP, IO, LS, CP), $\theta^i_{stories}$. Then the maximum drift constraint ratios, MCR_d, are calculated using Equation 2:

$$0 \leq MCR_d = \frac{\theta^i_{Stories}}{\theta^i_{all}} \leq 1 \qquad \text{where, I = OP, IO, LS, CP} \qquad (2)$$

The allowable relative drift values, θ^i_{all}, for performance levels OP, IO, LS and CP, in steel moment frame structures, are considered to be, respectively, 0.4%, 0.7%, 2.5% and 5%, based on FEMA-273 (1997), FEMA-350 (2000) and FEMA-356 (2000).

The performance of the proposed optimization algorithm is evaluated through comparing its optimum designs for three, 2D steel frame benchmark problems with results from some met heuristic optimization solutions to these problems, previously reported by other investigators. These comparisons lead to the following conclusions:

1- The main advantage of the simple CCM, compared to other optimization algorithms, is in its remarkable solution speed, requiring only a fraction of the number of structural analyses to reach the optimum solution, compared to all the met heuristic algorithms. This method is particularly suitable for performance-based seismic design optimization, as each analysis is very time-consuming.

2- In all benchmark problems, the proposed CCM lead to a design lighter than the reported met heuristic optimization solutions, except in the last example (six-storey, three-bay frame) in which it was marginally heavier than the ACO and HS solutions and 7.6% heavier than PSO design.

3- In all three benchmark problems, it appeared that the drift constraint related to the performance-based design (PBD), somewhat dominate the forced-based stress constraint, as the latter constraint ratios barely reached unity.

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