NEIGHBOUR MATRIX FOR OPTIMAL SEISMIC DESIGN OF RC FRAMES FOR MINIMUM TOTAL LIFE-CYCLE COST

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Despite the nonlinear performance of structures under probable severe earthquakes in their lifetime, conventional methods cannot easily assist for optimal seismic design structures with the performance objectives. In this paper, an inventive algorithm is introduced to overcome this problem. Convincingly, convergence is likely to occur even with different variables. Objective function in this study is the total life-cycle cost.

Inspired by the Simulated Annealing (SA) algorithm, a novel optimization algorithm is introduced for seismic design of RC frames, which the structures are discretely indicated with indicator vectors. For instance, for each 5-story RC frame, an indicator vector consisting of design variables is defined:

$$IV_j = \left[c_{j6} c_{j5} c_{j4} c_{j3} c_{j2} c_{j1} \right] \quad (1)$$

where IV_i is an indicator vector for j[th] RC frame, and c_{j6} to c_{j4} cj6 to cj4 and c_{j3} to c_{j1} cj6 to cj4cj3 to cj1components are the index numbers for the reinforcements of columns and beams, respectively. These numbers are equal to the ratio of the maximum to the minimum of the main reinforcement of the beams (upper face) or the main reinforcements of the columns (longitudinal reinforcements). Results vector and neighbour matrix were defined, then started the process with an initial RC frame that can bear vertical service loads and have near minimum allowable reinforcements in elements. For each RC frame, a group of Neighbor RC (RC_N) frames is defined. RC_N frame is an RC frame that except a component, all components of its indicator vector are the same with the main RC frame. This different component is a further amount more (+a) or less (-a) than the corresponding number of the main RC frame's indicator vector. M_N is a matrix where the first row represents the indicator vector of the main RC frame, and other rows shows the indicator vectors of the RC_N frames. Equation 2 is a M_N for a 5-story RC frame with IV_k indicator:

$$M_N = \begin{bmatrix} c_{k6} & c_{k5} & c_{k4} & c_{k3} & c_{k2} & c_{k1} \\ c_{k6} & c_{k5} & c_{k4} & c_{k3} & c_{k2} & c_{k1}+a \\ c_{k6} & c_{k5} & c_{k4} & c_{k3} & c_{k2} & c_{k1}-a \\ c_{k6} & c_{k5} & c_{k4} & c_{k3} & c_{k2}+a & c_{k1} \\ & & & .... & & \end{bmatrix} \quad (2)$$

If r_j is the objective parameter extracted from the nonlinear analysis of the j[th] RC frame with IV_j indicator vector, the result vector (R) is defined as follows, where each component is r_j:

$$R_N = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ \dots \end{bmatrix} \quad (3)$$

In each step, all the neighbour RC frames were stored in the optimum set. By calculation a transform vector (T) in each step, a new RC frame was created as Equation 4:

$$M_N \times T_N = R_N \qquad T_N = (M_N^T \times M_N)^{-1} \times (M_N^T \times R_N) \tag{4}$$

If possible, for the negative value t_i of matrix T_N, one step increase and for the t_i greater than 1.0, one step decrease the respective reinforcements of the current RC frame (c_{ki}), to create a new RC frame. Besides, if possible, create a new RC frame, assign the counter of steps, a further number more ($k_{new} = k+1$). This operation was repeated until stops, when there is no potential for further reduction or increase. The minimum result in the optimum set was regarded as the optimum value, for the optimum RC frame.

The IDARCV7.0 (Reinhorn et al., 2009) software was used for nonlinear dynamic analysis of structures under earthquake excitations. Natural ground motions were scaled by the design spectrum according to ASCE7-16 (2016).

The social costs associated with the occurrence of earthquakes ($C_s(\boldsymbol{x}_d)$) was included in addition to the initial construction cost ($C_0(\boldsymbol{x}_d)$) and the cost of repairs for damage caused by earthquakes at some time during the life of the structure ($C_d(\boldsymbol{x}_d)$) as Equation 6 (Möller et al., 2015):

$$C(x_d) = C_0(x_d) + C_d(x_d) + C_s(x_d) \tag{5}$$

where social cost consists of costs of re-insertion into a normal routine, medical and rehabilitation costs for non-fatal injured victims, costs associated with loss of fatality, and costs associated with loss of business or economic activities. Tables 1 shows the process of changing the objective functions for the problem.

Table 1. Summary results for optimal design with the first objective function.

		Step0	Step1	Step2	Step3	Step4	Step5	Step6	Step7
5-story	$\mathbf{x}_j$ numbers in this step	0	7	14	22	31	41	52	**62**
	Minimum TLCC	1480	1033.7	906.1	872.2	757.6	682.8	682.8	**672.2**
8-story	$\mathbf{x}_j$ numbers in this step	0	9	18	30	41	53	63	**74**
	Minimum TLCC	1722.1	1318.9	1318.9	1318.9	1238.2	1109	987.4	**987.4**
12- story	$\mathbf{x}_j$ numbers in this step	0	9	20	30	**40**	-	-	-
	Minimum TLCC	2762	2052.9	1682.9	1630.3	**1630.3**	-	-	-

It displays that after two steps, in all three investigated RC frames (5- 8- and 12 storey), total life-cycle cost (TLC) of the initial structure was decreased about an average of 25%. Besides, after all steps, the reduction for the optimum was from 52 to 80 percent. The efficiency evaluation of the proposed algorithm is presented in Table 2.

The advantages of the introduced novel optimization algorithm are the flexibility to use it for different objectives and achieve the optimal structure with a small number of analyses.

Table 2. The efficiency evaluation of the proposed algorithm.

Reduction in Initial Steps (%)	Reduce Obj. Function after 2 Steps (%)	Total Number of Analyzed Frames	Percentage of Optimization (%)
5-story	39	62	55
8-story	24	74	43
12-story	39	40	41

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