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Analysis and Optimum Design for Steel Moment Resisting Frames to Seismic Excitation using combination of ELF and NTH methods

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Abstract— *The essential purpose of this wander is to develop an Interior Penalty Function (IPF) based estimation to multi-storey steel traces for slightest weight of frames. The frames are proposed for contradicting even impact in view of seismic stacking close by gravity forces. Various structural stems are used for restricting seismic (lateral) forces; however steel moment resisting frames (MRFs) are considered for the present work. The framework solidifies codal courses of action of IS 800-2007, as needs be gets the edges with perfect weight for in-plane moments with lateral support of beam element. Strength and buckling criteria are considered as direct goals close by side constraints in formulating optimization problem. A Software program is made that uses an interior penalty function (IPF) for weight minimization of two-dimensional moment restricting steel encompassed structures. The program uses MATLAB, performs one dimensional interest, and structural design in an iterative technique. The design cases have exhibited that the proposed estimation gives a beneficial instrument to the practicing fundamental algorithm. The program is associated with 6 and 9 storey (4 bays) moment resisting frames (MRFs). The program showed its capacity of optimizing the largeness of two medium size frames. To get part obliges in frames an examination technique must be associated. In the present work Equivalent Lateral Force framework (ELF) and material nonlinear time history analysis (NTH) are associated and perfect qualities gained from both the examinations are contemplated.*

Keywords— IPF, MRF, ELF and NTH methods

I. INTRODUCTION

The main objective of the present project is to develop optimum weight design procedure for steel seismic force resisting systems using interior penalty function method with constrained objective function. The seismic force resisting systems considered are; steel moment resisting frames. The other objective of this study is to investigate the seismic resistance of steel moment resisting frames equipped with diagonal buckling restrained braces. The basis for the development of the new design methodology is limit state design procedure laid in Indian code for structural steel design IS: 800-2007.

Moment Resisting Frames (MRFs), demonstrating of building casings, breaking down by Equivalent Lateral Force (ELF) system and correlation of investigation results got from SAP 2000 bundle. The principle center of the venture is additionally taken a toll examination of these edges. These frames were acquainted with U.S. configuration hone in 1999, and their utilization has been generally as a building's essential seismic-stack opposing framework. It showed up in the US after the Northridge seismic tremor in 1994. In the repercussions of the 6.7-Richter-size Northridge seismic tremor of January 17, 1994, fall of stopping structure of California State University, Northridge grounds is indicated Figure 1. It is presently acknowledged with its outline directions in current models as a relocation subordinate parallel load opposing arrangement.

Fig. 1: Parking structures that collapsed during the 1994 Northridge earthquake, California State University,

II. LITERAURE REVIEW

E. Kalkan and S. K. Kunnath(2004) revealed in their study that the suitability of using unique modal combinations to determine lateral load configurations that best approximate the inter-story demands in multi-storey moment resisting frame buildings subjected to seismic loads. Akshay Gupta and Helmut Krawinkler (1999), in their Report No. 132, sponsored by the SAC Joint Venture considered MRFs emphasized on behaviour assessment and quantification of global and local force and deformation demands for different hazard levels Krishnan et al. (2006) studied the responses of tall steel moment frame buildings in scenario magnitude 7.9 earthquakes on the southern San Andreas Fault. This work used three-dimensional, nonlinear finite element models of an existing eighteen-story moment frame building as is, and redesigned to satisfy the 1997 Uniform Building Code. The authors found that the simulated responses of the original building indicate the potential for significant damage throughout the San Fernando and Los Angeles basins. The redesigned building fared better, but still showed significant deformation in some areas. The rupture on the southern San Andreas that propagated north-to-south induced much larger building responses than the rupture that propagated south-to-north. Thomas Heaton, et al. (2007) simulates the response of 6 and 20-story steel moment-resisting frame buildings (US 1994. UBC) for ground motions recorded in the 2003 Tokachi-oki earthquake. They consider buildings with both perfect welds and also with brittle welds similar to those observed in the 1994 Northridge earthquake. Their simulations show that the long-period ground motions recorded in the near-source regions of the 2003 Tokachi-oki earthquake would have caused large inter-story drifts in flexible steel moment-resisting frame buildings designed according to the US 1994.UBC. 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.

III. METHEDOLOGY

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.

Table.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; 4th digit indicates number of storeys.

The yield stress of the structural steel was taken as 250MPa. The considered model building frames details are given in table 1 and elevations are shown in Fig. 2&3.

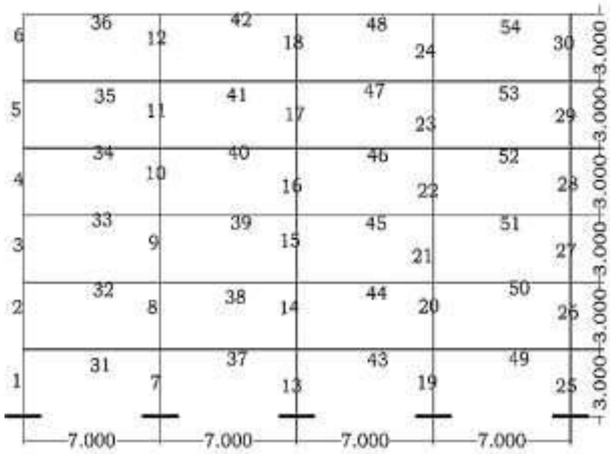

Fig. 2: Elevation of 6-storey steel MRF 6 & 9 floors each 3.00m and four bays each 7.00m respectively

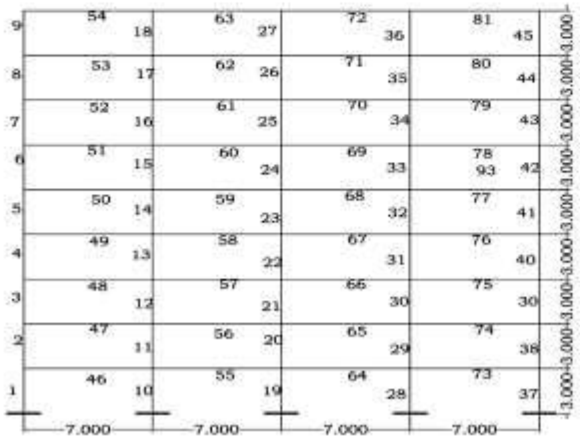

Fig. 3: Elevation of 9-storey steel MRF 6 & 9 floors each 3.00m and four bays each 7.00m respectively

The model building frames were analysed using Equivalent Lateral Force (ELF) Procedure which are briefly described in the following sections

Analysis by using ELF Procedures:

1. Evaluate the approximate period T_a of the fundamental vibration mode using an expression for steel frame building $T_a = 0.085\ h^{0.75}$ (eq.1)

   Where: h = Height of building, in m. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns.

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2. The design horizontal seismic coefficient (A_h) for a structure shall be determined by the following expression: $A_h=(Z/2)(I/R)(S_a/g)$ (eq.2)
   Where: Z=Zone factor for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Max. Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).
3. The seismic resultant design base shear (V_b) shall be computed by the following expression; $V_b=A_h W$
   Where: W=Seismic weight of building-(eq.3).
4. V_b shall be distributed over the height of the structure into a number of storey forces. Internal forces and displacements of the structure under the force V_b, by using a static analysis shall be established.
5. These seismic action effects shall be combined to other action effects. Carried out all seismic checks required for the structural elements.

*Table.2: Design Forces for **6** Storey Steel MRF–ELF analysis*

Column No	Pu (kN)	Mu1(kNm)	Mu2(kNm)	Beam No	Vu (kN)	Mu (kNm)
Floor Frame-06 (Roof)						
6	169.08	104.552	151.602	36	178.124	209.865
12	355.36	5.435	11.861	42	169.970	199.193
18	346.58	1.884	3.356	48	169.979	191.257
24	355.26	1.61	5.072	54	162.528	155.510
30	170.13	105.427	155.51	-		
Floor Frame-05						
5	345.15	90.51	82.983	35	171.131	196.851
11	702.31	0.965	0.62	41	171.372	203.040
17	694.91	3.916	5.176	47	170.244	199.090
23	702.11	7.007	11.049	53	170.597	195.227
29	348.32	94.194	89.799	-		
Floor Frame-04						
4	519.59	89.416	89.385	34	172.757	200.586
10	1050.97	5.725	6.732	40	171.303	203.405
16	1042.21	5.466	6.28	46	171.207	203.053
22	1050.54	5.445	6.043	52	169.607	190.236
28	525.90	95.151	97.063	-		
Floor Frame-03						
3	693.02	86.376	87.122	33	173.775	204.361
9	1400.33	6.674	6.882	39	171.615	204.458
15	1389.55	6.45	6.761	45	171.473	203.939
21	1399.60	6.501	6.906	51	168.857	187.841
27	703.11	93.592	95.085	-		
Floor Frame-02						
2	865.43	92.084	86.825	32	174.788	208.107
8	1750.62	12.503	9.924	38	171.692	204.747
14	1736.83	7.194	6.55	44	171.617	204.463
20	1749.56	2.272	3.513	50	166.535	178.039
26	879.57	100.833	94.248	-		
Floor Frame-01						
1	1035.98	27.830	72.901	31	176.655	212.964
7	2103.39	8.921	6.439	37	171.092	203.063
13	2083.37	8.708	4.162	43	171.744	205.312
19	2101.97	8.599	2.143	49	170.588	201.348
25	1053.70	43.378	77.206	-		

The ELF Procedure was the last step in the analysis process before proportioning of frame members. This includes calculating the story forces for each individual level, assigning it in SAP2000 and running the simulation to get our deflection by elasticity test result. The forces in the members of MRFs are computed by using ELF procedure and presented in tables 2 and 3

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Table.3: Design Forces for 9 Storey Steel MRF–ELF analysis

Column No	Pu (kN)	Mu1(kNm)	Mu2(kNm)	Beam No	Vu (kN)	Mu (kNm)
Floor Frame-09 (Roof)						
9	166.72	106.500	167.907	54	159.260	176.033
18	325.98	3.969	3.122	63	159.264	187.312
27	327.32	-1.421	-3.461	72	158.268	-183.851
36	326.04	-6.574	-9.723	81	158.322	-172.941
45	167.66	-106.181	-171.373	-		
Floor Frame-08						
8	340.10	94.979	99.905	53	163.596	-199.790
17	644.96	11.077	12.876	62	159.597	188.640
26	654.37	-3.262	-5.288	71	158.520	184.887
35	645.11	-17.440	-23.248	80	165.425	206.349
44	342.87	-102.002	-100.169	-		
Floor Frame-07						
7	512.41	96.864	94.979	52	162.525	-194.884
16	-1597.70	0.425	3.227	61	159.639	189.315
25	-1949.79	-8.480	-7.382	70	159.402	188.491
34	-2244.48	-13.125	-13.870	79	165.365	205.086
43	518.02	-101.150	-103.080	-		
Floor Frame-06						
6	-683.47	-94.500	93.714	51	161.280	-190.577
15	1285.76	3.227	2.680	60	160.113	190.899
24	1307.00	-6.381	-7.607	69	159.689	189.416
33	1285.85	-15.980	-17.856	78	164.946	203.739
42	692.75	-100.578	-102.585	-		
Floor Frame-05						
5	-853.36	-92.029	91.916	50	-160.101	-186.416
14	-1607.49	-0.497	0.425	59	160.353	-191.829
23	-1633.32	7.382	-8.191	68	160.008	-190.623
32	-1607.46	15.314	-6.834	77	164.379	-201.773
41	-866.91	99.471	-1.193	-		
Floor Frame-04						
4	-1021.94	-89.300	89.807	49	-158.79	-181.836
13	-1930.37	2.401	-1.821	58	160.497	-192.438
22	-1959.57	8.078	-8.480	67	160.230	-191.499
31	-1930.19	13.870	-15.229	76	163.488	-198.680
40	65.67	97.795	-99.209	-		
Floor Frame-03						
3	-1189.09	-6.320	87.540	48	158.828	-181.944
12	-2254.65	4.365	-3.866	57	160.527	-192.676
21	-2285.7	8.622	-8.421	66	160.382	-192.161

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30	-2254.26	13.037	-3.125	75	162.288	-194.486
39	-1212.25	95.903	-6.691	-		
Floor Frame-02						
2	-1354.62	-87.699	84.948	47	-155.75	-187.713
11	-2580.58	12.046	-7.534	56	160.500	-192.621
20	-2611.86	9.416	-7.548	65	160.316	-191.967
29	-2579.95	7.081	-7.800	74	160.611	-188.715
38	-1382.64	99.642	-2.813	-		
Floor Frame-01						
1	1518.27	25.462	75.958	46	-153.86	-163.657
10	2909.08	9.995	-2.732	55	159.824	-190.617
19	2937.54	11.975	-3.745	64	160.130	-191.673
28	2908.19	13.990	-4.911	73	157.871	-178.083
37	1550.30	47.132	78.440	-		

Once this result has been obtained, we are able to test if the model building frames have to satisfy the requirement for max allowable story drift. An equivalent static analysis is conducted to determine the member forces in the frame members and the horizontal drifts in the storeys. It is assumed that all connections are rigid (moment) connections in the frame. Where: Pu=Factored axial force; Vu=Factored beam shear force; Mu=Factored beam bending moment; Mu1=Factored top end moment in columns; Mu2=Factored bottom end moment in columns.

Analysis by using NTH Procedures:

The elastic analysis pertains to structural systems which have elastic- linear inertia, damping and restoring forces. Whenever the structural system has any or all of the three reactive forces having non-linear variation with the response parameters (i.e., displacement, velocity, and acceleration), a set of non-linear differential equations are evolved and need to be solved. The most common non-inearity among the three are; stiffness and damping non-linearities. In the stiffness non-linearity, two types of non-linearity may be encountered, namely, the geometric non-linearity and the material non-linearity. The present study deals material non-linearity. Because the equations of motion for multi-degrees of freedom (MDOF) system are a set of coupled non-linear differential equations, their solutions are difficult to obtain analytically. Most of the solution procedures are numerical based and obtain the solution by solving the incremental equations of motion. The incremental equations of motion make the problem linear over the small time interval Δt. The solution is then obtained using the techniques for solving the linear differential equations. However, under certain conditions, iterations are required at each time step in order to obtain the current solution.

*Table.4: Design Forces for **6** Storey Steel MRF*–NTH analysis

Floor Frame-06 (Roof)						
Column No	Pu (kN)	Mu1(kNm)	Mu2(kNm)	Beam No	Vu (kN)	Mu (kNm)
6	156.47	96.760	140.422	36	164.85	194.304
12	328.85	-3.203	-7.698	42	157.31	184.429
18	320.74	0.000	0.000	48	157.88	186.422
24	32.88	3.203	7.698	54	163.88	-189.251
30	157.44	-95.461	-139.619	-		
Floor Frame-05						
5	319.45	84.015	78.550	35	158.43	182.406
11	649.95	2.747	5.305	41	158.64	188.131
17	643.10	0.000	0.000	47	157.60	184.475
23	649.76	-2.747	-5.305	53	157.93	180.927
29	322.39	-83.970	-78.550	-		
Floor Frame-04						

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4	480.97	83.913	84.762	34	159.98	186.027
10	972.60	-0.128	-0.314	40	158.62	188.621
16	964.49	0.000	0.000	46	158.54	188.294
22	972.20	0.128	0.314	52	157.41	177.431
28	486.80	-83.908	-84.762	-		
Floor Frame-03						
3	641.59	81.817	82.834	33	160.96	189.656
9	1295.91	-0.079	0.011	39	158.95	189.724
15	1285.91	0.000	0.000	45	158.82	189.240
21	1295.24	0.079	-0.011	51	157.47	-176.711
27	650.91	-81.817	-82.834	-		
Floor Frame-02						
2	801.30	87.704	82.322	32	161.92	193.205
8	1620.07	-4.652	-2.915	38	159.04	190.066
14	1607.26	0.000	0.000	44	158.97	189.801
20	1619.09	4.652	2.915	50	158.19	-179.277
26	814.34	-87.704	-82.319	-		
Floor Frame-01						
1	959.27	32.372	68.282	31	163.64	197.648
7	1946.50	-0.146	-1.953	37	158.47	188.453
13	1927.93	0.000	0.000	43	159.07	190.530
19	1945.20	0.146	1.953	49	160.32	-185.296
25	975.63	-32.372	-68.241			

The frames along with rigid supports shown in Figure 2 to 3 were analyzed for Bhuj earthquake data using NTH procedure. Direct integration of the full equations of motion without the use of modal superposition is performed using SAP 2000. The direct integration analyses performed with decreasing time-step sizes until the step size is small enough that results satisfy convergence criteria of 0.001. (Which type of method you are using? Either Eigen value analysis or direct integration). The forces in the members of MRFs are computed by using NTH analysis and tabulated in tables 4 and 5.

Table.5: Design Forces for ***9*** *Storey Steel MRF*–NTH analysis

Column No	Pu (kN)	Mu1(kNm)	Mu2(kNm)	Beam No	Vu (kN)	Mu (kNm)
Floor Frame-09 (Roof)						
9	77.35	47.437	72.126	54	71.70	81.462
18	149.66	0.093	-2.231	63	71.09	84.294
27	149.45	-1.483	-3.663	72	70.69	82.926
36	149.69	-2.878	-4.861	81	70.68	-78.065
45	78.38	-47.117	-75.897			
Floor Frame-08						
8	157.14	42.079	36.867	53	71.47	-84.304
17	296.37	1.459	0.745	62	71.60	86.058
26	298.93	-3.440	-5.621	71	71.16	84.550
35	296.46	-8.235	-11.839	80	73.44	91.379
44	160.14	-44.342	-44.262			
Floor Frame-07						
7	236.07	40.487	38.625	52	70.61	-80.704
16	443.61	-1.886	-3.964	61	71.93	87.415
25	448.09	-5.306	-7.109	70	71.82	87.023

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34	443.66	-8.710	-10.218	79	73.66	91.646
43	242.12	-45.073	-47.304			
Floor Frame-06						
6	314.28	39.021	37.725	51	70.84	81.523
15	591.13	-3.714	-4.764	60	72.38	88.936
24	597.33	-6.772	-8.095	69	72.19	88.274
33	591.08	-9.876	-11.445	78	73.82	92.292
42	324.26	-45.510	-47.219			
Floor Frame-05						
5	-383.54	36.948	39.021	50	71.47	83.700
14	739.00	-5.417	-6.044	59	72.65	89.942
23	746.53	-7.842	-8.717	68	72.50	89.424
32	738.80	-10.374	-11.475	77	73.84	92.376
41	406.41	-45.600	-46.866			
Floor Frame-04						
4	468.83	36.332	36.159	49	72.08	85.825
13	887.30	-6.989	-7.063	58	72.83	90.605
22	895.69	-8.590	-9.027	67	72.72	90.201
31	886.90	-10.356	-11.133	76	73.67	91.799
40	488.40	-45.386	-46.200			
Floor Frame-03						
3	545.22	34.723	35.443	48	72.66	87.845
12	1036.11	-7.969	-7.703	57	72.90	90.895
21	1044.80	-9.177	-8.964	66	72.84	90.688
30	1035.47	-10.583	-10.419	75	73.32	90.591
39	570.03	-44.946	-45.205	-----		
Floor Frame-02						
2	621.07	35.539	35.233	47	73.20	89.786
11	1185.50	-11.527	-8.507	56	72.86	90.753
20	1193.91	-10.055	-8.036	65	72.79	90.502
29	1184.59	-8.904	-7.834	74	72.72	88.533
38	651.07	-48.255	-43.587	-----		
Floor Frame-01						
1	696.48	4.369	32.432	46	73.64	90.871
10	1335.89	-12.249	-3.942	55	72.30	88.931
19	1342.84	-12.792	-3.942	64	72.43	89.364
28	1334.71	-13.389	-4.122	73	71.36	83.306
37	730.75	-27.528	-35.051			

Solving constrained optimization problems is generally cumbersome, there are methods such as the feasible directions method that solves the constrained problems directly, the main strategy behind the penalty methods is to change the form of the above constrained optimization problem to an unconstrained form so that unconstrained optimization techniques can be applied. To this end, a global objective function, called the penalty function.

With Output Case is COMBO1 and Case type is combination of Frame elements.

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*Table.6: Element Joint Frames-Frames for **6** Stories Steel MRF*

Frame	Joint	F_1-kN	F_2	F_3-kN	M_1	M_2(kN-M)	M_3	Frame element
1	1	22.473	0	645.77	0	20.1304	0	1
1	2	-22.473	0	-641.094	0	47.2893	0	1
2	2	39.373	0	539.559	0	62.2292	0	2
2	3	-39.373	0	-534.882	0	55.8903	0	2
3	3	38.624	0	432.094	0	58.7367	0	3
3	4	-38.624	0	-427.417	0	57.1359	0	3
4	4	39.652	0	323.847	0	60.1806	0	4
4	5	-39.652	0	-319.17	0	58.7746	0	4
5	5	38.986	0	214.932	0	60.8002	0	5
5	6	-38.986	0	-210.255	0	56.157	0	5
6	6	56.545	0	105.526	0	65.9763	0	6
6	7	-56.545	0	-100.849	0	103.6576	0	6
7	8	-1.984	0	1282.963	0	-3.1815	0	7
7	9	1.984	0	-1278.29	0	-2.7715	0	7
8	9	-2.006	0	1068.319	0	-2.6587	0	8
8	10	2.006	0	-1063.64	0	-3.3596	0	8
9	10	0.921	0	854.667	0	2.3729	0	9
9	11	-0.921	0	-849.99	0	0.3894	0	9
10	11	1.23	0	641.387	0	2.8615	0	10
10	12	-1.23	0	-636.71	0	0.8278	0	10
11	12	4.84	0	428.373	0	6.2866	0	11
11	13	-4.84	0	-423.696	0	8.2345	0	11
12	13	-1.023	0	216.053	0	-1.2194	0	12
12	14	1.023	0	-211.376	0	-1.8491	0	12
13	15	-1.991	0	1274.524	0	-3.6623	0	13
13	16	1.991	0	-1269.85	0	-2.3117	0	13
14	16	-0.564	0	1062.333	0	0.0447	0	14
14	17	0.564	0	-1057.66	0	-1.7361	0	14
15	17	0.819	0	849.888	0	2.1659	0	15
15	18	-0.819	0	-845.211	0	0.2901	0	15
16	18	1.363	0	637.476	0	2.9144	0	16
16	19	-1.363	0	-632.799	0	1.174	0	16
17	19	3.09	0	425.107	0	4.6746	0	17
17	20	-3.09	0	-420.43	0	4.5953	0	17
18	20	1.491	0	212.346	0	1.2569	0	18
18	21	-1.491	0	-207.669	0	3.2157	0	18
19	22	-1.299	0	1277.658	0	-3.5295	0	19
19	23	1.299	0	-1272.98	0	-0.3664	0	19
20	23	2.289	0	1061.814	0	4.9396	0	20
20	24	-2.289	0	-1057.14	0	1.9273	0	20
21	24	2.143	0	849.213	0	4.037	0	21
21	25	-2.143	0	-844.536	0	2.3924	0	21
22	25	2.799	0	637.352	0	4.9974	0	22
22	26	-2.799	0	-632.675	0	3.3988	0	22
23	26	3.153	0	428.99	0	5.5462	0	23
23	27	-3.153	0	-424.313	0	3.9137	0	23
24	27	4.958	0	216.3	0	5.789	0	24
24	28	-4.958	0	-211.623	0	9.0848	0	24
25	29	-26.404	0	678.844	0	-27.4457	0	25
25	30	26.404	0	-674.167	0	-51.7652	0	25
26	30	-40.636	0	570.397	0	-61.9412	0	26

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26	31	40.636	0	-565.72	0	-59.9673	0	26
27	31	-38.18	0	458.218	0	-56.0477	0	27
27	32	38.18	0	-453.541	0	-58.4927	0	27
28	32	-38.99	0	343.735	0	-57.163	0	28
28	33	38.99	0	-339.058	0	-59.808	0	28
29	33	-35.182	0	228.996	0	-55.0733	0	29
29	34	35.182	0	-224.32	0	-50.4714	0	29
30	34	-55.944	0	110.431	0	-67.3334	0	30
30	35	55.944	0	-105.754	0	-100.5	0	30
31	2	-16.889	0	101.534	0	-109.519	0	31
31	9	16.889	0	106.265	0	126.0764	0	31
32	3	0.793	0	102.788	0	-114.627	0	32
32	10	-0.793	0	105.011	0	122.4092	0	32
33	4	-0.928	0	103.57	0	-117.317	0	33
33	11	0.928	0	104.229	0	119.6219	0	33
34	5	0.843	0	104.238	0	-119.575	0	34
34	12	-0.843	0	103.561	0	117.2031	0	34
35	6	-17.282	0	104.729	0	-122.133	0	35
35	13	17.282	0	103.071	0	116.3294	0	35
36	7	56.843	0	100.849	0	-103.658	0	36
36	14	-56.843	0	106.95	0	125.0121	0	36
37	9	-16.85	0	103.702	0	-120.646	0	37
37	16	16.85	0	104.097	0	122.0268	0	37
38	10	-2.067	0	103.964	0	-121.422	0	38
38	17	2.067	0	103.836	0	120.9746	0	38
39	11	-1.088	0	104.374	0	-122.873	0	39
39	18	1.088	0	103.425	0	119.5518	0	39
40	12	-2.502	0	104.776	0	-124.318	0	40
40	19	2.502	0	103.023	0	118.1819	0	40
41	13	-11.005	0	104.572	0	-123.345	0	41
41	20	11.005	0	103.227	0	118.6367	0	41
42	14	56.316	0	104.426	0	-123.163	0	42
42	21	-56.316	0	103.374	0	119.4799	0	42
43	16	-18.261	0	103.417	0	-119.76	0	43
43	23	18.261	0	104.382	0	123.1361	0	43
44	17	-3.384	0	103.932	0	-121.404	0	44
44	24	3.384	0	103.867	0	121.1768	0	44
45	18	-1.483	0	104.31	0	-122.756	0	45
45	25	1.483	0	103.489	0	119.8838	0	45
46	19	-3.964	0	104.669	0	-124.031	0	46
46	26	3.964	0	103.13	0	118.6459	0	46
4	20	-8.991	0	104.857	0	-	0	47

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7						124.489		
47	27	8.991	0	102.943	0	117.7904	0	47
48	21	58.303	0	104.295	0	-122.696	0	48
48	28	-58.303	0	103.504	0	119.9256	0	48
49	23	-16.882	0	105.612	0	-123.696	0	49
49	30	16.882	0	102.188	0	111.7116	0	49
50	24	7.344	0	105.262	0	-123.108	0	50
50	31	-7.344	0	102.538	0	113.5741	0	50
51	25	9.558	0	105.334	0	-123.259	0	51
51	32	-9.558	0	102.465	0	113.2186	0	51
52	26	15.088	0	105.514	0	-123.756	0	52
52	33	-15.088	0	102.285	0	112.4535	0	52
53	27	-2.048	0	105.007	0	-122.778	0	53
53	34	2.048	0	102.792	0	115.0254	0	53
54	28	63.757	0	108.119	0	-129.01	0	54
54	35	-63.757	0	99.68	0	99.4728	0	54
61	22	2.634	0	4.554	0	-4.4925	0	55
61	30	-2.634	0	1.583	0	1.9949	0	55
62	23	-4.947	0	1.173	0	-4.0136	0	56
62	31	4.947	0	4.964	0	2.4409	0	56
63	24	-10.501	0	-1.204	0	-4.0332	0	57
63	32	10.501	0	7.341	0	2.437	0	57
64	25	-11.515	0	-1.64	0	-4.0149	0	58
64	33	11.515	0	7.777	0	2.4277	0	58
65	26	-19.083	0	-4.959	0	-3.8344	0	59
65	34	19.083	0	11.096	0	2.7795	0	59
66	27	-8.243	0	0.063	0	-4.7149	0	60
66	35	8.243	0	6.074	0	1.0273	0	60
67	36	-0.0037	0	6.137	0	21.4682	0	61
67	37	0.0037	0	1.37E-13	0	2.13E-15	0	61
68	38	6.541	0	7.129	0	0.0244	0	62
68	39	-6.541	0	-0.992	0	0.0014	0	62
69	40	-1404.2	0	3792.179	0	-86.7098	0	63
69	41	1404.2	0	-3786.04	0	1.4527	0	63
70	42	14.984	0	0.828	0	-0.0061	0	64
70	43	-14.984	0	5.309	0	-0.0174	0	64
71	44	9.332	0	4.043	0	-0.0629	0	65
71	45	-9.332	0	2.094	0	-0.07	0	65
72	46	-12.592	0	12.088	0	0.1111	0	66
72	47	12.592	0	-5.951	0	0.0717	0	66

With Output Case is COMBO1 and Case type is combination of Frame elements.

*Table.7: Element Joint Frames-Frames for **9** Stories Steel MRF*

Frame	Joint	F_1.kN	F_2	F_3.kN	M_1	M_2(kN-M)	M_3	Frame element
1	1	22.538	0	1012.178	0	16.9749	0	1
1	2	-22.538	0	-1005.655	0	50.6386	0	1
2	2	38.366	0	903.082	0	58.4658	0	2
2	3	-38.366	0	-896.559	0	56.6321	0	2

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3	3	38.636	0	792.726	0	57.5469	0	3	
3	4	-38.636	0	-786.204	0	58.3598	0	3	
4	4	39.801	0	681.291	0	59.5332	0	4	
4	5	-39.801	0	-674.769	0	59.8711	0	4	
5	5	40.877	0	568.906	0	61.3525	0	5	
5	6	-40.877	0	-562.383	0	61.277	0	5	
6	6	41.825	0	455.649	0	63.0003	0	6	
6	7	-41.825	0	-449.127	0	62.4757	0	6	
7	8	42.632	0	341.607	0	64.5759	0	7	
7	9	-42.632	0	-335.084	0	63.3191	0	7	
8	9	42.932	0	226.734	0	66.6033	0	8	
8	10	-42.932	0	-220.212	0	62.1938	0	8	
9	10	60.979	0	111.148	0	71	0	9	
9	11	-60.979	0	-104.625	0	111.9377	0	9	
10	11	-2.828	0	1939.384	0	-6.6633	0	10	
10	12	2.828	0	-1932.862	0	-1.8211	0	10	
11	12	-4.351	0	1720.388	0	-8.0305	0	11	
11	13	4.351	0	-1713.865	0	-5.0229	0	11	
12	13	-1.829	0	1503.102	0	-2.9103	0	12	
12	14	1.829	0	-1496.579	0	-2.5773	0	12	
13	15	-0.938	0	1286.914	0	-1.6006	0	13	
13	16	0.938	0	-1280.392	0	-1.2138	0	13	
14	16	0.205	0	1071.656	0	0.3314	0	14	
14	17	-0.205	0	-1065.134	0	0.283	0	14	
15	17	1.313	0	857.173	0	2.1512	0	15	
15	18	-1.313	0	-850.651	0	1.7866	0	15	
16	18	2.083	0	643.318	0	3.8733	0	16	

16	19	-2.083	0	-636.795	0	2.3745	0	16	
17	19	5.323	0	429.975	0	7.3846	0	17	
17	20	-5.323	0	-423.452	0	8.5843	0	17	
18	20	1.576	0	217.318	0	2.6463	0	18	
18	21	-1.576	0	-210.795	0	2.0813	0	18	
19	22	-3.493	0	1958.357	0	-7.9836	0	19	
19	23	3.493	0	-1951.834	0	-2.4964	0	19	
20	23	-3.77	0	1741.24	0	-6.2771	0	20	
20	24	3.77	0	-1734.718	0	-5.0322	0	20	
21	24	-3.787	0	1523.797	0	-5.7482	0	21	
21	25	3.787	0	-1517.275	0	-5.6138	0	21	
22	25	-3.679	0	1306.38	0	-5.3852	0	22	
22	26	3.679	0	-1299.857	0	-5.6532	0	22	
23	26	-3.461	0	1088.881	0	-4.9216	0	23	
23	27	3.461	0	-1082.359	0	-5.4607	0	23	
24	27	-3.109	0	871.331	0	-4.2546	0	24	
24	28	3.109	0	-864.808	0	-5.0716	0	24	
25	29	-2.598	0	653.727	0	-3.3392	0	25	
25	30	2.598	0	-647.205	0	-4.4537	0	25	
26	30	-1.9	0	436.248	0	-2.1748	0	26	
26	31	1.9	0	-429.726	0	-3.525	0	26	
27	31	-1.085	0	218.21	0	-0.9473	0	27	
27	32	1.085	0	-211.688	0	-2.3075	0	27	
28	32	-4.2	0	1938.792	0	-9.3268	0	28	
28	33	4.2	0	-1932.27	0	-3.2738	0	28	
29	33	-3.307	0	1719.965	0	-4.7208	0	29	

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29	34	3.307	0	-1713.443	0	-5.2002	0	29
30	34	-5.814	0	1502.842	0	-8.6915	0	30
30	35	5.814	0	-1496.319	0	-8.7499	0	30
31	2	-6.466	0	1286.791	0	-9.2469	0	31
31	9	6.466	0	-1280.269	0	-10.1526	0	31
32	3	-7.144	0	1071.642	0	-10.209	0	32
32	10	7.144	0	-1065.12	0	-11.2228	0	32
33	4	-7.519	0	857.236	0	-10.6531	0	33
33	11	7.519	0	-850.713	0	-11.9043	0	33
34	5	-7.24	0	643.42	0	-10.5021	0	34
34	12	7.24	0	-636.897	0	-11.2181	0	34
35	6	-9.042	0	430.075	0	-11.6268	0	35
35	13	9.042	0	-423.552	0	-15.4989	0	35
36	7	-3.622	0	217.357	0	-4.3826	0	36
36	14	3.622	0	-210.834	0	-6.4821	0	36
37	9	-27.905	0	1033.532	0	-31.4215	0	37
37	16	27.905	0	-1027.01	0	-52.2936	0	37
38	10	-42.768	0	921.763	0	-66.4281	0	38
38	17	42.768	0	-915.241	0	-61.8751	0	38
39	11	-42.799	0	808.167	0	-63.935	0	39
39	18	42.799	0	-801.644	0	-64.4605	0	39
40	12	-43.779	0	693.453	0	-65.1969	0	40
40	19	43.779	0	-686.93	0	-66.139	0	40
41	13	-44.592	0	577.939	0	-66.3142	0	41
41	20	44.592	0	-571.416	0	-67.4623	0	41
42	14	-45.148	0	461.83	0	-67.0528	0	42
42	21	45.148	0	-455.308	0	-68.3903	0	42
43	16	-45.386	0	345.343	0	-67.4357	0	43
43	23	45.386	0	-338.821	0	-68.7229	0	43
44	17	-44.927	0	228.578	0	-68.001	0	44
44	24	44.927	0	-222.056	0	-66.7793	0	44
45	18	-61.679	0	111.772	0	-70.7874	0	45
45	25	61.679	0	-105.25	0	-114.249	0	45
46	19	-15.819	0	102.574	0	-109.104	0	46
46	26	15.819	0	108.224	0	128.8822	0	46
47	20	-0.233	0	103.833	0	-114.179	0	47
47	27	0.233	0	106.965	0	125.1422	0	47
48	21	-1.083	0	104.913	0	-117.893	0	48
48	28	1.083	0	105.885	0	121.2958	0	48

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49	23	-0.928	0	105.863	0	-121.224	0	49
49	30	0.928	0	104.935	0	117.9786	0	49
50	24	-0.72	0	106.734	0	-124.277	0	50
50	31	0.72	0	104.064	0	114.9325	0	50
51	7	-0.476	0	107.52	0	-127.052	0	51
51	17	0.476	0	103.278	0	112.2023	0	51
52	8	0.148	0	108.35	0	-129.922	0	52
52	18	-0.148	0	102.448	0	109.2648	0	52
53	9	-17.46	0	109.064	0	-133.194	0	53
53	19	17.46	0	101.734	0	107.5395	0	53
54	10	61.53	0	104.625	0	-111.938	0	54
54	20	-61.53	0	106.173	0	117.3556	0	54
55	12	-14.282	0	104.249	0	-119.031	0	55
55	22	14.282	0	106.549	0	127.0783	0	55
56	13	-2.701	0	103.798	0	-117.209	0	56
56	23	2.701	0	107	0	128.4141	0	56
57	14	-1.852	0	103.78	0	-117.118	0	57
57	24	1.852	0	107.018	0	128.4505	0	57
58	15	-1.854	0	103.8	0	-117.096	0	58
58	25	1.854	0	106.998	0	128.2916	0	58
59	16	-1.488	0	103.896	0	-117.36	0	59

						7		
59	26	1.488	0	106.902	0	127.8859	0	59
60	17	-0.757	0	104.056	0	-117.862	0	60
60	27	0.757	0	106.742	0	127.2658	0	60
61	18	-2.426	0	104.372	0	-119.024	0	61
61	28	2.426	0	106.426	0	126.21	0	61
62	19	-12.843	0	104.4	0	-118.77	0	62
62	29	12.843	0	106.398	0	125.7609	0	62
63	20	64.015	0	104.622	0	-119.437	0	63
63	30	-64.015	0	106.176	0	124.8749	0	63
64	22	-13.992	0	104.045	0	-118.305	0	64
64	32	13.992	0	106.753	0	127.7823	0	64
65	23	-2.629	0	103.921	0	-117.634	0	65
65	33	2.629	0	106.877	0	127.9782	0	65
66	24	-1.838	0	103.877	0	-117.452	0	66
66	34	1.838	0	106.921	0	128.1071	0	66
67	25	-1.855	0	103.978	0	-117.717	0	67
67	35	1.855	0	106.82	0	127.6661	0	67
68	26	-1.5	0	104.126	0	-118.171	0	68
68	36	1.5	0	106.672	0	127.0815	0	68
69	27	-0.779	0	104.339	0	-118.855	0	69
69	37	0.779	0	106.459	0	126.2774	0	69

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70	28	-2.458	0	104.531	0	-119.582	0	70
70	38	2.458	0	106.268	0	125.6607	0	70
71	29	-12.788	0	105.118	0	-121.289	0	71
71	39	12.788	0	105.68	0	123.2584	0	71
72	30	63.84	0	105.512	0	-122.567	0	72
72	40	-63.84	0	105.286	0	121.7759	0	72
73	32	-14.872	0	105.551	0	-119.788	0	73
73	42	14.872	0	105.247	0	118.7217	0	73
74	33	-0.067	0	103.724	0	-114.086	0	74
74	43	0.067	0	107.074	0	125.8102	0	74
75	34	-1.063	0	102.607	0	-110.11	0	75
75	44	1.063	0	108.192	0	129.6575	0	75
76	35	-0.96	0	101.806	0	-107.305	0	76
76	45	0.96	0	108.992	0	132.4532	0	76
77	36	-0.785	0	101.212	0	-105.206	0	77
77	46	0.785	0	109.586	0	134.5151	0	77
78	37	-0.568	0	100.834	0	-103.871	0	78
78	47	0.568	0	109.964	0	135.8261	0	78
79	38	0.01	0	100.555	0	-102.816	0	79
79	48	-0.01	0	110.243	0	136.7238	0	79
80	39	-17.338	0	100.515	0	-103.377	0	80
80	49	17.338	0	110.283	0	137.5668	0	80
81	40	61.128	0	105.548	0	-115.294	0	81
81	50	-61.128	0	105.25	0	114.2487	0	81

Optimum design of MRF members:

The columns and beams of steel MRFs are taken as welded I-sections and subjected to internal forces. Columns are subjected to axial compressive forces and bending moments and the effect of shear is ignored wherein in beams the axial force in ignored and shear force and bending moments are considered.

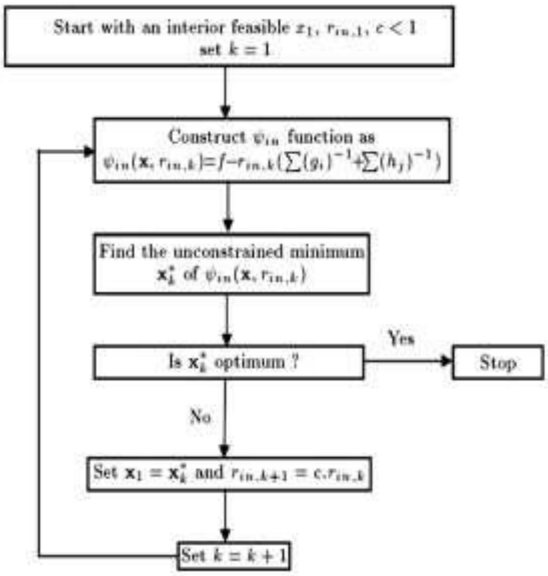

Fig. 4: Flow chart for interior penalty function

With the assumption that the beam is subjected to shear and bending moment the behaviour constraint modifies keeping all other constraints remaining same due to the effect of shear. The optimization algorithm developed is applied to MRFs and the results.

IV. RESULTS AND DISCUSSION

The results of the analysis and optimum design. The analysis includes both ELF procedure and NTH analysis for steel MRFs of 6 and 9 floors. Also the optimum design variables and objective function values are presented in tables 8 to 11.

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*Table.8: Design Forces for **6** Storey Steel MRF using ELF procedures*

Floor -06 (Roof)-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
6/36	10.685/11.855	179.512/222.867	10.258/10613	430.830/445.733	195.659/553.798
12/42	6.000/11.650	91.555/219.023	6.000/10.430	219.731/438.046	57.284/534.861
18/48	6.000/11.493	65.778/216.075	6.000/10.289	157.867/432.150	41.156/520.558
24/54	6.000/10.727	72.522/201.675	6.000/9.604	174.053/403.150	45.376/453.486
30/-	10.774/-	180.996/-	10.343	434.391/-	198.907/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*538.382+2062.702=* ***2601.084***

Floor -05-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
5/35	9.394/11604	157.815/218.161	9.018/10.389	378.755/436.323	151.219/530.660
11/41	7.205/11.725	121.043/220.424	6.000/10.496	252.000/440.848	77.172/541.725
17/47	6.904/11.648	115.991/218.985	6.000/10.428	206.347/437.971	67.302/534.676
23/53	7.205/11.572	121.043/217.560	6.000/10.360	252.000/435.119	77.172/527.737
29/-	9.509/-	159.748/-	9.128/-	383.395/-	154.946/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*527.812+2134.799=* ***2662.610***

Floor -04-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
4/34	9.669/11.110	162.435/208.870	9.282/9.946	389.844/417.741	160.203/486.424
10/40	8.565/11.73	143.892/220.556	6.000/10.503	238.697/441.112	92.360/542.374
16/46	8.526/11.725	143.243220.429	6.000/10.497	233.431/440.858	91.085/541.748
22/52	8.560/11.473	143.808/215.690	6.000/10.271	231.152/431.379	91.219/518.704
28/-	9.897/-	166.276/-	9.502/-	399.061/-	167.868/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*602.735+2089.251=* ***2691.985***

Floor -03-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
3/33	9.909/11.750	166.471/220.901	9.513/10.519	399.529/441.802	168.262/544.072
9/39	9.925/11.752	166.737/220.936	6.000/10.521	252.000/441.872	114.274/544.244
15/145	9.880/11.742	165.986/220.749	6.000/10.512	250.974/441.498	113.423/543.323
21/51	9.924/11.425	166.728/214.781	6.000/10.228	252.000/429.561	114.265/514.341
27/-	10.148/-	170.478/-	9.742/-	409.147/-	176.460/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*686.683+2145.981=* ***2832.664***

Floor -02-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
2/32	10.347/11.	173.822/222.2	9.933/10.5	417.173/444.4	183.451/550.

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	821	43	83	85	701
8/38	21.845/11.757	105.000/221.040	6.000/10.526	252.000/442.080	144.557/544.757
14/44	20.013/11.752	105.000/220.938	6.000/10.521	252.000/441.876	135.440/544.253
20/50	23.473/11.222	89.547/210.978	6.000/10.047	214.914/421.956	130.191/496.289
26/-	10.597/-	178.029/-	10.173/-	427.269/-	192.438/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*786.077+2136.000=* ***2922.077***

Floor -01-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
1/31	10.375/11.913	174.295/223.958	9.495/10.665	398.787/447.917	175.450/559.236
7/37	25.047/11.725	105.000/220.432	6.000/10.497	252.000/440.865	160.494/541.766
13/43	24.736/11.768	105.000/221.243	6.000/10.535	252.000442.486	158.943/545.759
19/49	24.929/11.692	105.000219.810	6.00010.67	252.000439.620	159.906/538.711
25/-	10.483/-	176.122/-	9.683/-	406.689/-	180.848/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					835.641+2185.473= **3021.114**

Table 9 Design Forces for 9Storey Steel MRF using ELF procedures

Floor -09 (Roof)-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
9/54	11.035/11.180	185.389/210.183	10.594/10.009	444.934/420.365	208.679/492.554
18/63	6.000/11.414	65.851/21.579	6.000/10.218	158.042/429.158	41.201/513.375
27/72	6.000/11.343	64.169/213.249	6.000/10.155	154.005/426.498	40.149/507.032
36/81	6.000/11.114	83.475/208.945	6.000/9.950	200.341/417.889	52.229/486.769
45/-	11.109/-	186.625/-	10.664/-	447.900/-	211.471/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*553.730+1999.731=* ***2553.461***

Floor -08-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
8/53	9.659/11.662	162.279/219.242	9.273/10.440	389.469/438.483	159.895/535.929
17/62	7.135/11.441	119.865/215.085	6.000/10.242	252.000/430.170	76.372/515.799
26/71	6.690/11.364	112.396/213.649	6.000/10.174	205.880/427.298	64.919/508.935
35/80	7.985/11.788	134.148/221.615	6.463/10.553	271.428/443.230	92.346/547.595
44/-	9.723/-	163.350/-	9.334/-	392.040/-	162.013/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*555.544+2108.258=* ***2663.801***

Floor -07-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
7/52	9.869/11.566	165.794/217.432	9.474/10.354	397.905/434.864	166.896/527.119
16/61	15.000/11.454	125.412/215.341	6.000/10.254	220.481/430.682	120.520/517.029

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25/70	12.188/11.438	190.018/215.028	6.000/10.239	285.010/430.056	150.301/515.527
34/79	15.000/11.764	125.412/221.162	6.000/10.532	220.481/442.324	120.520/545.358
43/-	10.048/-	168.810/-	9.646/-	405.144/-	173.024/-
***Total Floor Weight (kg)** =Column No. total of Ø-Values +Beam No. total of Ø-Values*					*731.261+2105.033=* ***2836.295***

Floor -06-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
6/51	10.098/11.480	169.643/215.819	9.694/10.277	407.143/431.637	174.737/519.324
15/60	15.000/11.486	100.498/215.940	6.000/10.283	208.058/431.880	101.040/519.909
24/69	9.625/11.456	161.700/215.379	6.000/10.256	252.000/430.759	109.606/517.213
33/78	9.463/11.738	158.973/220.677	6.001/10.508	351.999/441.353	121.359/542.968
42/-	10.329/-	173.521/-	9.916/-	416.451/-	182.817/-
***Total Floor Weight (kg)** =Column No. total of Ø-Values +Beam No. total of Ø-Values*					*689.559+2099.413=* ***2788.971***

Floor -05-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
5/50	10.324/11.396	173.447/214.236	9.911/10.202	416.274/428.472	182.662/511.737
14/59	15.000/11.505	124.507/216.290	6.000/10.300	193.759/432.580	116.077/521.596
23/68	14.787/11.481	131.015/215.836	6.000/10.278	272.366/431.672	130.560/519.407
32/77	10.635/11.700	178.669/219.965	6.000/10.475	337.377/439.929	138.043/539.469
41/-	10.541/-	177.092/-	10.120/-	425.020/-	190.418/-
***Total Floor Weight (kg)** =Column No. total of Ø-Values +Beam No. total of Ø-Values*					*757.759+2092.209=* ***2849.969***

Floor -04-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
4/49	10.557/11.301	177.352/212.467	10.134/10.118	425.645/424.934	190.978/503.320
13/59	15.000/11.517	151.653/216.519	6.000/10.310	224.672/433.037	139.774/522.699
22/67	15.000/11.498	155.314/216.166	6.000/10.294	284.565/432.332	150.893/520.997
31/76	15.000/11.640	150.088/218.835	6.000/10.421	201.992/437.670	135.436/533.942
40/-	9.172/-	154.083/-	8.805/-	369.800/-	144.152/-
***Total Floor Weight (kg)** =Column No. total of Ø-Values +Beam No. total of Ø-Values*					761.233+2080.959= **2842.192**

Floor -03-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
3/48	11.095/11.304	186.390/212.509	10.086/10.120	423.629/425.018	199.287/503.520
12/57	15.000/11.522	178.285/216.608	6.000/10.315	254.673/433.216	162.975/523.130
21/66	15.000/11.511	181.400/216.415	6.000/10.306	295.091/432.830	170.938/522.198
30/75	12.637/11.558	212.301/217.284	6.000/10.347	333.230/434.568	174.552/526.401
39/-	11.245/-	188.922/-	10.408/-	437.144/-	208.533/-

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Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	916.285+2991.533=**2991.533**

Floor -02-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
2/47	11.697/11.422	196.506/214.732	10.062/10.225	422.585/429.464	209.718-514.108
11/56	13.541/11.521	227.122/216.587	6.000/10.314	332.721/433.175	193.091-523.031
20/65	15.000/11.508	207.524/216.342	6.000/10.302	310.874/432.684	191.756-521.846
29/74	15.000/11.442	204.852/215.113	6.000/10.244	295.886/430.227	187.725-515.936
38/-	11.891/-	199.774/-	10.510/-	441.401/-	222.544/-
Total Floor Weight (kg) =*Column No. total of Ø-Values +Beam No. total of Ø-Values*					*1004.833+2074.920* ***=3079.753***

Floor -01-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
1/46	12.148/10.912	204.087/205.137	9.555/9.768	401.299/410.273	208.390/469.189
10/55	15.000/11.481	231.358/215.834	6.000/10.278	323.175/431.667	210.451/519.397
19/64	15.000/11.502	233.656/216.231	6.000/10.297	340.327/432.463	214.524/521.313
28/73	15.000/11.223	233.656/210.995	6.000/10.047	340.327/421.990	217.061/496.371
37/-	12.275/-	206.226/-	9.657/-	405.599/-	212.825/-

Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	1063.250+2006.269 =**3069.519**

Table 10 Design Forces for ***6*** *Storey Steel MRF using NTH procedures*

Floor -06-Roof: Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
6/36	11.157/11.554	187.442/217.216	6/10.344	449.860/434.433	163.099/526.073
12/42	6/11.355	78.072/213.472	6.000/10.165	187.373/426.945	48.848/508.094
18/48	6.924/11.396	116.330/214.239	6.000/10.202	279.193/428.477	77.883/511.748
24/54	6/11.453	78.065/215.317	6.000/10.253	187.355/430.634	48.844/516.912
30/-	11.13/-	187.094/-	6/-	449.025/-	162.613/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*501.286+2062.827=* ***2564.113***

Floor -05-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
5/35	9.673/11.313	162.507/212.689	6.000/10.128	390.017/425.378	129.970/504.372
11/41	6.666/11.430	111.996/214.891	6.000/10.233	205.891/429.782	64.647/514.871
17/47	8.715/11.356	146.406/213.490	6.000/10.166	351.373/426.980	110.441/508.179
23/53	6.665/11.283	111.979/212.113	6.000/10.101	205.882/425.225	64.665/501.642
29/-	9.678/-	162.558/-	6.000/-	390.211/-	130.806/-

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Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	*499.806+2029.062=* ***2528.868***

Floor -04-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
4/34	10.057/11.388	168.9592/214.087	6.000/10.195	405.501/428.174	138.206/511.025
10/40	15.000/11.440	73.137/215.078	6.000/10.242	162.851/430.155	75.158/515.764
16/46	8.577/11.434	144.088/214.953	6.000/10.236	345.812/429.906	107.752/515.168
22/52	15.000/11.209	173.105/210.737	6.000/10.035	162.830/421.475	75.132/495.159
28/-	10.070/-	169.175/-	6.000/-	406.020/-	138.486/-

Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	534.733+2037.116= **2571.848**

Floor -03-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
3/33	10.308/11.461	173.174/215.470	6.000/10.261	415.617/430.941	143.713/517.649
9/39	15.000/11.463	98.887/215.496	6.000/10.262	175.695/430.992	95.293/517.773
15/45	8.662/11.453	145.519/215.313	6.000/10.253	349.246/430.625	109.409/516.892
21/51	15.000/11.194	98.911/210.452	6.000/10.022	176.288/420.904	95.394/493.818
27/-	10.365/-	174.124/-	6.000/-	417.897/-	144.968/-

Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	588.776+2046.133= **2634.909**

Floor -02-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
2/32	10.860/11.532	182.445/216.806	6.000/10.324	437.868/433.612	156.180-524.087
8/38	10.709/11.469	179.909/215.625	6.000/10.268	431.781/431.251	152.721-518.395
14/44	9.348/11.464	156.669/215.525	6.000/10.263	374.210/431.050	122.635-517.913
20/50	10.709/11.248	179.909/211.466	6.000/10.070	431.781/422.931	152.721-498.587
26/-	10.709/-	179.909/-	6.000/-	431.781/-	152.721/-

Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	*736.978+2058.982=* ***2795.960***

Floor -01-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
1/31	10.548/11.066	177.206/207.939	6.000/9.9019	425.295/415.8779	149.076/532.100
7/37	11.017/11.437	185.092/215.137	6.000/10.2387	444.221/430.0274	159.828/515.458
13/43	12.240/11.479	205.626/215.815	6.000/10.2762	493.503/431.6014	189.472/519.249
19/49	10.585/11.373	177.820/213.863	6.000/10.1813	426.767/427.6126	149.900/509.686
25/-	10.585/-	177.820/-	6.000/-	426.768/-	149.900/-

Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*	798.175+2076.4728

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	=2874.648

Table 11 Design Forces for ***9*** *Storey Steel MRF using NTH procedures*

Floor -09-Roof:Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
9/54	8.648/8.648	145.284/162.574	6/7.742	348.681/325.147	109.135/294.687
18/63	8.680/8.747	145.396/164.436	6.067/7.830	348.014/328.872	109.854/301.478
27/72	6.000/8.699	47.859/163.542	6.000/7.788	114.862/327.084	29.945/298.207
36/81	6.000/8.526	52.685/160.282	6.000/7.633	126.443/320.563	32.964/286.437
45/-	8.812/-	148.040/-	6.000/-	355.295/-	112.357/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*394.255+1180.809=* ***1575.064***

Floor -08-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
8/53	7.321/8.747	122.998/164.443	6.000/7.831	295.196/328.885	84.661/301.502
17/62	6.000/8.807	53.182/165.575	6.000/7.885	127.637/331.151	33.275/305.670
26/71	6.000/8.755	68.840/164.603	6.000/7.838	165.216/329.205	43.072/302.088
35/80	6.000/8.985	86.384/168.920	6.000/8.044	207.321/337.840	54.049/318.143
44/-	7.463/-	125.381/-	6.000/-	300.914/-	87.144/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*302.200+1227.402=* ***1529.603***

Floor -07-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
7/52	7.442/8.621	125.024/162.068	6.000/7.718	300.058/324.136	86.770/292.856
16/61	6.000/8.853	83.113/162.068	6.000/7.926	176.896/332.882	48.792/308.874
25/70	6.000/8.840	87.883/166.192	6.000/7.914	210.919/332.384	54.987/307.950
34/79	6.000/8.994	95.601/169.084	6.000/8.052	229.442/338.168	59.815/318.762
43/-	7.847/-	131.832/-	6.000/-	316.398	94.028/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					344.392+1228.443= **1572.835**

Floor -06-Design Variables					
Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
6/51	7.572/8.650	127.213/162.614	6/7.744	305.312/325.228	89.075/294.834
15/60	6.337/8.904	106.457/167.401	6.000/7.972	196.351/334.802	59.897/312.447
24/69	6.357/8.882	106.791/166.985	6.000/7.952	238.241/333.969	66.054/310.895
33/78	6.485/9.015	108.942/169.481	6.000/8.071	261.462/338.961	70.666/320.259
42/-	8.060/-	135.399/-	6/-	449.025/-	97.934/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*383.626+1238.434=* ***1622.060***

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Floor -05-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
5/50	7.767/8.726	130.481/164.049	6.000/7.812	313.155/328.098	92.566/300.060
14/59	7.134/8.938	119.855/168.030	6.000/8.001	218.720/336.059	71.633/314.799
23/68	7.162/8.921	120.315/167.707	6.000/7.986	250.223/335.413	76.424/313.589
32/77	7.092/9.018	119.149/169.532	6.000/8.073	280.247/339.064	79.906/320.453
41/-	8.259/-	138.746/-	6.000/-	332.990/-	101.665
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*422.193+1248.900=* ***1671.093***

Floor -04-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
4/49	7.853/8.799	131.925/165.426	6/7.877	316.619/330.851	94.128/305.118
13/58	7.849/8.960	131.859/168.442	6/8.021	236.329/336.883	82.661/316.344
22/67	7.882/8.946	132.410/168.191	6/8.009	258.383/336.382	86.209/315.403
31/76	7.826/8.999	131.479/169.178	6/8.056	280.453/338.356	88.653/319.117
40/-	8.443/-	141.835/-	6.000/-	340.404/-	105.165/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					456.816+1255.981= **1712.797**

Floor -03-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
3/48	8.021/8.868	124.752/166.714	6.000/7.939	323.405/333.427	97.220/309.887
12/57	8.504/8.969	142.866/168.621	6.000/8.030	251.564337.242	93.360/317.019
21/66	8.538/8.962	143.443/168.493	6.000/8.024	264.669/336.986	95.690/316.537
30/75	8.493/8.959	142.676/168.433	6.000/8.021	278.922/336.866	97.097/316.311
39/-	8.610/-	144.655/-	6.000/-	3470172/-	108.406/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					491.773+1259.753= **1751.526**

Floor -02-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
2/47	8.244/8.933	138.503/167.933	6.000/7.997	332.408/335.865	101.392/314.435
11/56	9.106 8.965	152.974/168.533	6.000/8.025	292.478/337.006	107.615/316.668
20/65	9.144/8.956	153.624/168.378	6.000/8.018	278.1800336.755	106.144/316.104
29/74	9.110/8.891	153.045/167.148	6.000/7.959	266.2222334.295	103.9422311.502
38/-	8.972/-	150.734	6.000	361.762/-	115.548/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					*534.641+1258.729=* ***1793.370***

Floor -01-Design Variables

Column No /Beam No.	X1 (mm)	X2 (mm)	X3 (mm)	X4 (mm)	Ø-Values -kg
1/46	8.290/8.968	139.267/168.606	6.000 8.029	334.241/337.212	102.251/316.963

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10/55	9.681 /8.90 4	162.64 5/167.3 98	6.000 /7.97 1	303.36 5/334.7 95	117.77 5/312. 435
19/64	9.705 8.919	163.04 5167.6 69	6.000 /7.98 4	308.60 3/335.3 38	118.88 7/313. 449
28/73	9.672 8.712	162.49 4163.7 91	6.000 /7.80 0	313.89 7/327.5 82	119.13 4/299. 118
37/-	8.531 /-	143.32 4/-	6.000 /-	343.97 7/-	106.87 0/-
Total Floor Weight (kg) *=Column No. total of Ø-Values +Beam No. total of Ø-Values*					564.91 7+124 1.964= **1806.8** **81**

From the values obtained from optimization technique, graphs between number of storeys and storey optimum weight were plotted and presented in figures 5 and 6. As can be seen from the graph, the relationship of storey levels versus cost function is roughly linear.

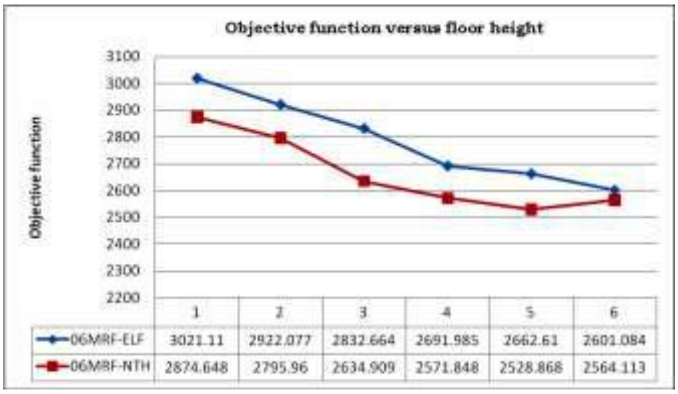

Fig. 5: Variation Objective Values with the Height of Steel MRF for 6 Storey Frame

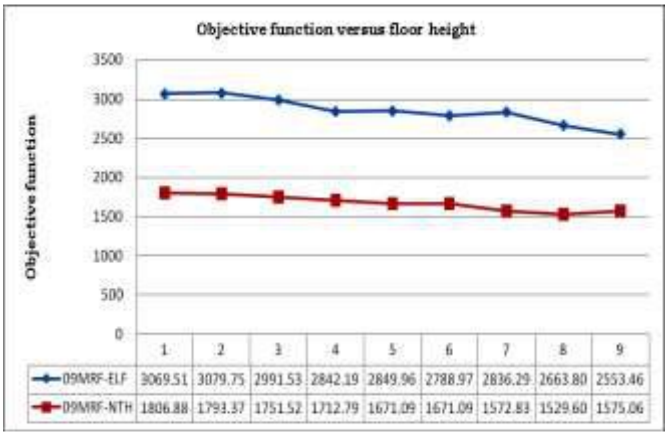

Fig. 5: Variation Objective Values with the Height of Steel MRF for 9 Storey Frame

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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