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AUTOMATIC ANALYSIS OF PLANE FRAMED STRUCTURES WITH SEMI-RIGID CONNECTIONS FOR COMBINED MULTIPLE LOAD SETS

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Abstract. Usually, the analysis and project of framed steel structures are developed under the assumption of a simplified behavior of the connections between beams and columns. Or the connection is total flexible (pinned), or is total rigid. A total flexible connection allows that the beam turns freely under the action of the loading without occurring transference of bending moment among the elements. Therefore, the rigid connection supports loads without that it has change of the original angle between its members. The experimental research shows that almost all of the connections present an intermediate behavior between these two extremes, allowing a parcel of relative rotation and transmitting of an element for the other, part of the operating moment, being classified as semi-rigid connections. In this work a Genetic Algorithm (GA) for the optimization and automatic analysis evaluation of commercial transversal sections of the structure is applied. Numerical examples are presented to illustrate the applicability of the algorithm multiple load sets in consideration the curves of the CRC (Column Research Council), the LRFD (American Institute of Steel Construction) and the NBR 8800 (Brazilian Association of Norms Techniques). The normal deformations are taken in consideration in the structural analysis Such methodology suggests a sizing of sections that can be used in the real world for the designers of steel structures and to show the possibility of economy at the order of 20%-30% in the sizing of the beams due to semi-rigid connections.

1 INTRODUCTION

Traditional approaches to steel frame design neglect the actual behavior of connections. Instead, two idealizations are used: pinned and fully rigid. Although these models simplify analysis and design procedures, the predicted response of the frame may not be realistic. In practice most connections transmit some moments and experience shows that some rotations can contribute substantially to overall structure displacements. The term semi-rigid is commonly used to denote the connection behavior between these two extremes. When a beam-column assembly is tested, for a given moment, a corresponding rotation is obtained for the beam plus connection.

The realization of the semi-rigid characteristics of beam to column connections and their effects on frame behavior can be traced back to the 1930s. Since then, a large amount of experimental and theoretical work has been conducted both on the behavior of the connections themselves and on their effects on the performance of complete frames. Batho and Rowan (1934) proposed the 'beam-line' method; this is a graphical method to predict the end restraint provided by connections for which the experimentally obtained moment-rotation curve (M - ϕ) must be known.

The Figure 1 shows a typical M - ϕ *curve* of various types of most common connections.

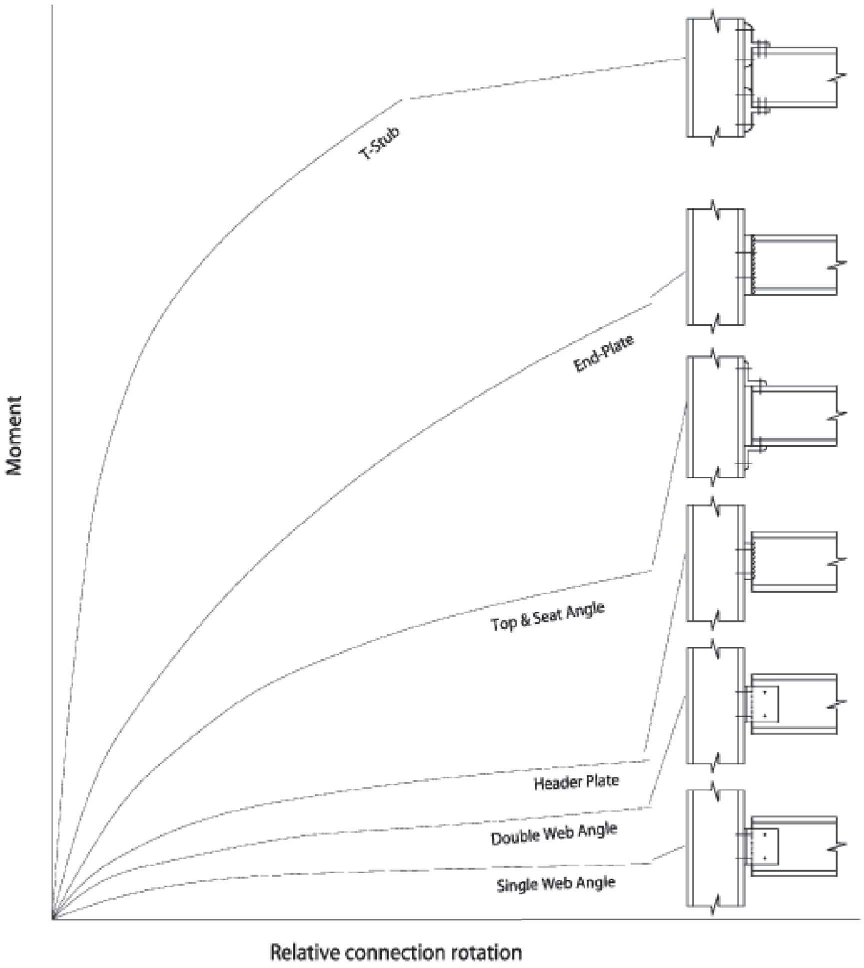

Figure 1: Connection moment-rotation curve

In a general way, the real behavior of the moment-rotation curve of the connections depends on factors such as (Morris and Packer, 1987):

- Type and size of the bolts;
- Distance of the bolts to the face of the column;
- Thickness of angle-irons and plates of joint;
- Height of the beam and the joint;
- Presence or not of stiffners in the column;
- If the joint is the flange or the web of the column;
- Thickness of the flange (or web) of the column;
- Yield strength of the beam, the column and the material of the joint;
- Poor and irregular maintenance.

In the 1930s, Baker (1931 and 1934) and Rathbun (1936) first applied the conventional slope deflection and moment distribution methods to the analysis of semi-rigid frames. A detailed review of the early development of semi-rigid frame analysis has been conducted by Jones *et al*. (1983).

The process of structural design is generally characterized by finite, often large, numbers of variables of the ‘discrete’ type. Universal steel beams available to the designer are discrete in dimensions and properties, even the thickness of a concrete slab is a discrete variable in that practical dimensions will vary by discrete intervals. Nothing is lost in generalization if it is assumed that all design variables can be described in discrete intervals. If we meet genuinely continuous variables, then these can always be discretized to conform to our assumption. A ‘feasible’ structural design is any combination of the variables which satisfies the design constraints. The complete set of feasible designs, usually a very large number, constitutes for ‘feasible design space’ and progress towards the optimum design will involve some kind of search of this space (combinatorial optimization). The search may be ‘deterministic’ in character where algorithmic methods are employed using, for example, gradient concepts, or it may be ‘stochastic’ where a random component is introduced. Whether the search is deterministic or stochastic it is usually possible to improve the reliability of the result, where ‘reliability’ means nearness to optimum, by spending more time on it. Briefly an optimum design is one which minimizes the objective function. One would usually base an objective function on cost but the ‘best’ structure is not necessarily the cheapest and other objectives may sometimes be important and may be used conveniently in studies in optimum design. The construction of a cost based objective is often very difficult due to lack of precise cost information suggesting that a total insistence on reaching a global optimum is hardly justified.

The purpose of this work is to describe the application of Genetic Algorithm for automatic analysis in weight optimization of framed structures with assumption of rigid and semi-rigid connections using American and Brazilian codes and also to show the possibility of having 20% cost economy reducting the size of the beams. Such method has only become possible with the powerful computing facilities now available.

2 GENETIC ALGORITHM

Among the stochastic direct search methods the ‘genetic algorithm’ is based on the principles of natural selection and survival of the fittest. The genetic analogy is maintained in the terminology used in the method.

In the following, the coding, selection, recombination, mutation, evaluation, and end procedures of the GA used here are summarized.

An initial 'population' is generated by random selection of the individual bits in a binary string of given length. The strings ('individuals') represent, directly or indirectly, the design variables in the objective function. Groups are formed, initially at random, to compose families of strings each family containing a single set of parameters comprising a design.

2.1 The Coding

The first step is to encode all the variables corresponding to a candidate solution in a chromosome. In this work it is adopted the standard binary coding (Eq. 1): each variable is encoded into a string of binary digits of a chosen length and these strings are then concatenated to form a single string which is an individual in the population of candidate solutions.

$$2^{\ell} = nv \tag{1}$$

Where ℓ is the string length and nv are the possible assumed values.

2.2 The Population size

The size of the population (n_{pop}) indicates the number of chromosomes that has in each population. The criterion for definition of the size of the population is still undefined, the choice depends on each problem and the experience acquired in the of the optimization process (Lemonge, 1999). Khan (2002) suggested in Eq. (2) that the size of the population will be between ℓ and 2ℓ.

$$\ell \leq n_{pop} \leq 2.\ell \tag{2}$$

2.3 The Selection

Here, the rank-based selection scheme is adopted (Baker, 1987). Given the current population, this selection scheme starts by sorting the population according to the values of the fitness function constructing a ranking, i.e. better solutions have higher rank. Individuals in the population are then selected in such a way that higher ranking individuals have a higher probability of being chosen for reproduction (Ochi and Rocha, 2000). This leads to an intermediate population whose elements will then be operated upon by the recombination and mutation operators.

2.4 The Recombination operator

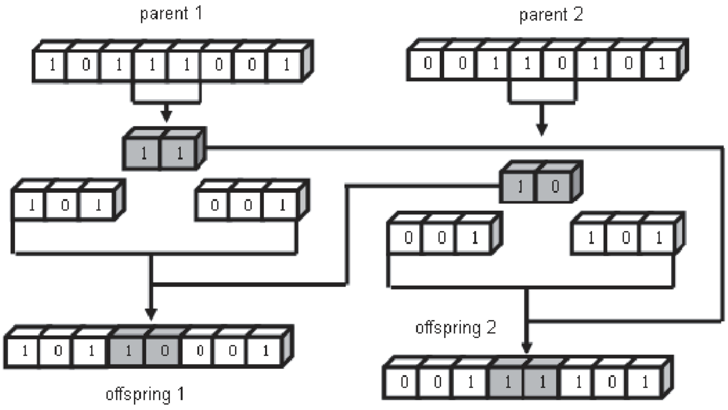

Figure 2: Two-point crossover operator

The recombination of the genetic material of the selected ‘parent’ chromosomes in order to generate the offspring chromosomes will be accomplished here using the two-point crossover operator (Figure2). The recombination operation is usually performed with a user-defined probability (p_c) and, consequently, with probability (1 - p_c), the operation is not performed and both parents are just copied and sent to the mutation operation step. Here p_c = 0,80.

2.5 Probability of mutation

The probability of mutation (p_m) indicates which content of one determined position of the chromosome will be modified (Figure3).

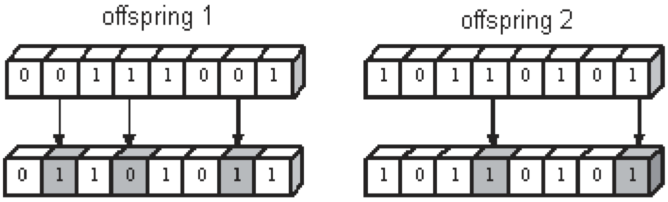

Figure 3: Mutation operator

The mutation is used to supply new information of the population, preventing that the new population become saturated with similar chromosomes and decreases the diversity of the population. High probabilities can become the search essentially random. Therefore some researchers recommend that the choice of the pm will be expressed in terms of the size of the chromosomes and the populations. Hesser and Manner (2000) suggest that an excellent pm can be found by the Eq. (3). This quantity shall be greater than 0,001.

$$p_m = \frac{1}{n_{pop}\sqrt{\ell}} \tag{3}$$

2.6 Evaluation and End of the evolution process

After each cycle of selection, crossover and, possibly, mutation, the fitness of each family is again assessed by converting the binary strings to decimal digits (decoding) and evaluating the objective function. The cycle then continues into the next generation. The numbers of individuals in population remains in the same number that its predecessors and substitute them for complete (Lucas, 2000). The end of process is the minimum weight found in 1000 generations.

3 METHOD OF ANALYSIS

By the 1960s, the Matrix Stiffness Method (MSM) of structural analysis utilizing computers had been established. Monforton and Wu (1963), Livesley (1964), and Gere and Weaver (1965) were the first to incorporate the effects of semi-rigid connections into the MSM. This was achieved by modifying the beam stiffness matrices to take the semi-rigid connection effects into account in the frame analysis. The basis of the method described herein is to consider the beam to column connection as an independent element which is free from both beams and columns. This enables the end rotational stiffnesses and stiffness matrix of the beams and columns for conventional analysis of rigid frames to remain unchanged in the analysis of semi-rigid frames. In addition, the analysis procedures for semi-rigid frames using this method remain the same as for normal frames. Thus semi-rigid frame analysis can be conducted using normal frame analysis programs simply by including the connection elements.

The fundamental connection parameters, i.e. its stiffness matrix and modified stiffness were, obtained from Soares Filho (2004) and applied in the MSM.

Equation (4) and Equation (6) present the modified stiffness matrix (K_{mod}) and stiffness matrix (K) respectively.

$$K_{\mathrm{mod}} = \begin{bmatrix} \frac{EA}{L} & & & & & \\ 0 & \frac{4EI(B_{11}+B_{12}+B_{22})}{L^3} & & & \textit{symetric} & \\ 0 & \frac{2EI(2B_{11}+B_{12})}{L^2} & \frac{4EIB_{11}}{L} & & & \\ -\frac{EA}{L} & 0 & 0 & \frac{EA}{L} & & \\ 0 & -\frac{4EI(B_{11}+B_{12}+B_{22})}{L^3} & -\frac{2EI(2B_{11}+B_{12})}{L^2} & 0 & \frac{4EI(B_{11}+B_{12}+B_{22})}{L^3} & \\ 0 & \frac{2EI(2B_{11}+B_{12})}{L^2} & \frac{2EIB_{12}}{L} & 0 & -\frac{2EI(2B_{11}+B_{12})}{L^2} & \frac{4EIB_{22}}{L} \end{bmatrix} \qquad (4)$$

In which:

$$\begin{cases} B_{11} = \dfrac{3P_1}{4-P_1P_2} \\ B_{12} = \dfrac{3P_1P_2}{4-P_1P_2} \\ B_{22} = \dfrac{3P_2}{4-P_1P_2} \end{cases} \qquad (5)$$

E: Elasticity modulus of steel;

A: Transversal area of the element;

L: Length of the element;

P_1 and P_2: side setting factor of connection, which varies of value zero for pinned to one for fully rigid connections.

$$K = \begin{bmatrix} \frac{EA}{L} & & & & & \\ 0 & \frac{12EI}{L^3} & & & \textit{symetric} & \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & & & \\ -\frac{EA}{L} & 0 & 0 & \frac{EA}{L} & & \\ 0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & 0 & \frac{12EI}{L^3} & \\ 0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{4EI}{L} \end{bmatrix} \qquad (6)$$

Note that if $P_1 = P_2 = 1{,}0$ the K_{mod} is equal the stiffness matrix (K).

Table 1 specifies the values of P_1 and P_2 for the considered connections in the numerical analysis.

		T-Stub	**Top and Seat Angle**	**Double Web Angle**
Left side of the beam	P_1	0,85	0,50	0,20
Right side of the beam	P_2	0,85	0,50	0,20

Table 1: Setting factor of connection

4 NUMERICAL ANALYSIS

The three-storey and ten-storey frames analyzed by Barakat and Chen (1990) and by Xu and Grierson (1993) respectively were considered to demonstrate the effect of various semi-rigid connections in the optimum design. Figure 4 and Figure 5 show the frames configurations, dimensions, multiple loading sets, and numbering of joints and grouping of members. The allowable nodal displacement of the top storey were 32, 50 mm and 87,45 mm respectively as specified by the AISC manual (2001) and NBR 8800 (2008).

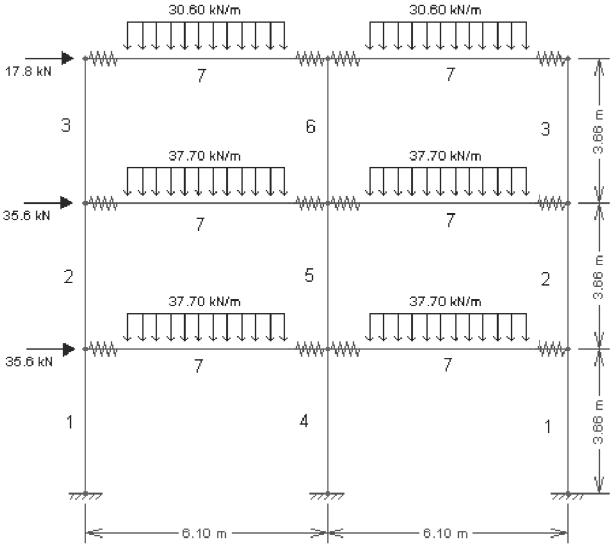

Figure 4: Three-storey steel frame

The steel grade of ASTM A36 is considered for all sections and the numbers of its available are 512, set from AISC manual (2001), also compatibles with ABNT steel. The objective function is defined as the weight of structure and showed in Eq. (7).

$$W = \sum \rho . L \tag{7}$$

Where ρ is the nominal weight of the bar.

From Eq. (1) we have for each variable:

$$2^{\ell} = nv$$

$$2^{\ell} = 512$$

$$\ell = 9$$

Then for the three-storey frame $\ell = 63$ and for the ten-storey frame $\ell = 180$, because the frames have seven and twenty variables respectively.

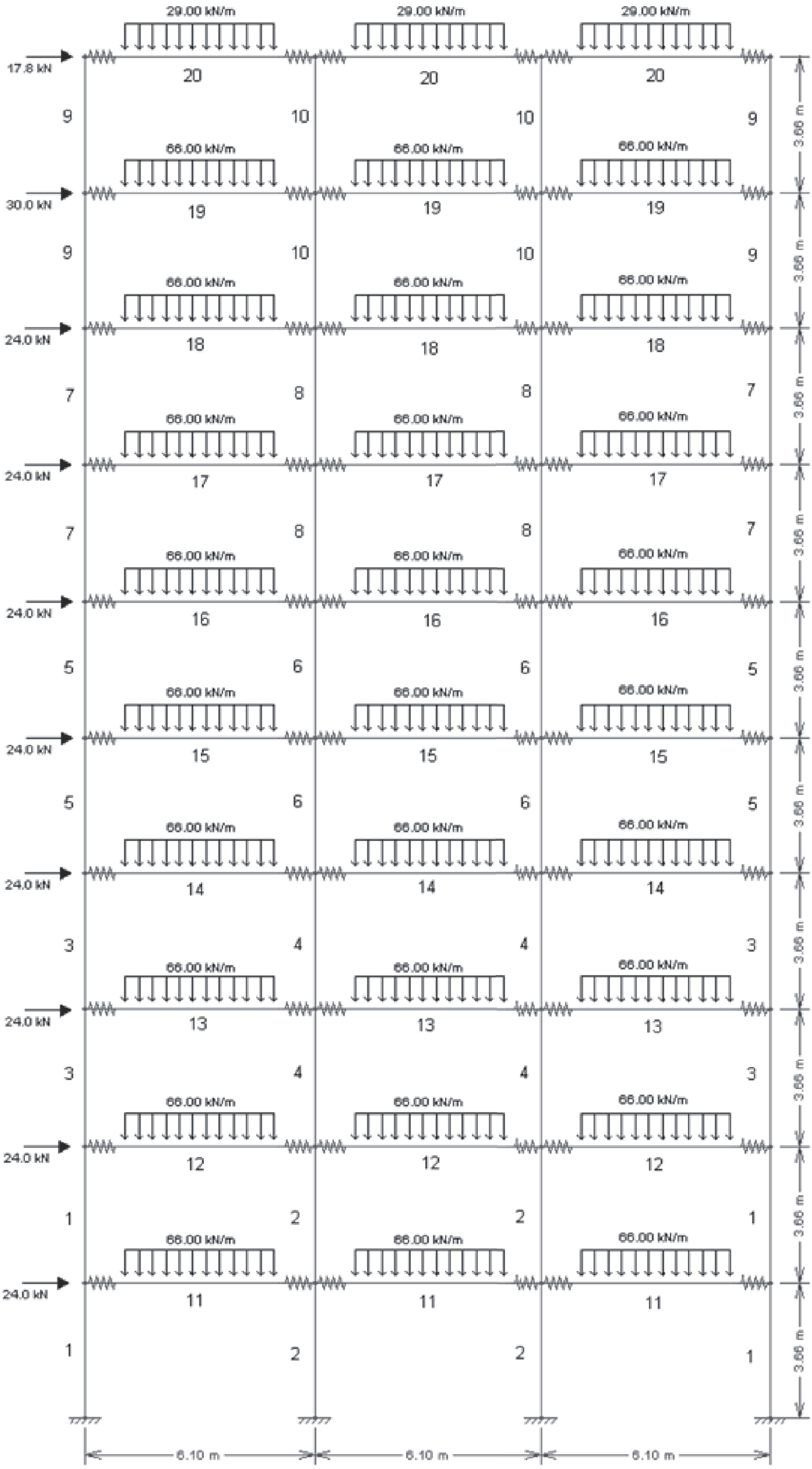

Figure 5: Ten-storey steel frame

From Eq. (2) n_{pop} =100 and 200 respectively, and finally for Eq. (3) obtain the mutation probability (p_m) for the two examples which are 0,001.

The routine for structural analysis is based on program ELFO (Harrison, 1973) and the routine for genetic algorithm is based on Castro (2005). Figure 6 show the Flow chart for combined program.

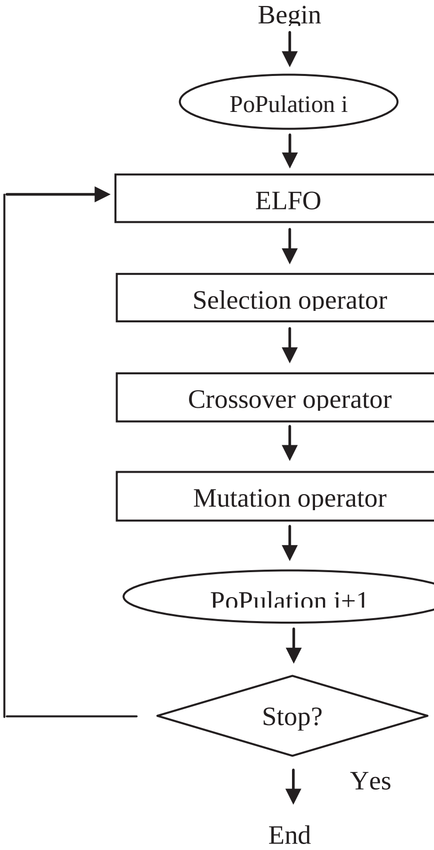

Figure 5: Programs ELFO and GA combined.

The optimum results obtained for designs with rigid and semi-rigid connections considering linear effect behavior of the frames using the LRFD are presented in Table 2 and Table 3.

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W21X50	W24X55	W21X73	W21X68
2	**Column**	W21X50	W21X44	W21X50	W21X50
3	**Column**	W18X35	W12X26	W18X40	W16X26
4	**Column**	W27X84	W30X108	W21X62	W21X62
5	**Column**	W24X55	W24X55	W21X50	W21X44
6	**Column**	W18X46	W18X35	W18X40	W18X40
7	**Beam**	W14X26	W14X26	W14X22	W14X26
Total weight (kg)		**3891,82**	**3853,72**	**3799,28**	**3777,52**
Total Beams weight (kg)		**1415,21**	**1415,21**	**1197,40**	**1415,21**
Beams economy weight ratio (%)		**-**	**0,00**	**15,39**	**0,00**

Table 2: Final design for the three-storey frame using LRFD

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W33X424	W33X424	W33X387	W33X387
2	**Column**	W24X76	W33X468	W33X263	W33X291
3	**Column**	W33X387	W18X311	W33X263	W18X291
4	**Column**	W33X387	W33X387	W33X387	W33X387
5	**Column**	W33X141	W18X311	W33X141	W18X175
6	**Column**	W33X141	W33X130	W33X130	W27X368
7	**Column**	W24X492	W18X76	W24X492	W18X143
8	**Column**	W21X201	W27X194	W27X194	W30X326
9	**Column**	W18X65	W18X65	W18X50	W18X65
10	**Column**	W18X65	W18X35	W18X50	W18X65
11	**Beam**	W24X76	W21X57	W21X50	W21X57
12	**Beam**	W21X50	W21X68	W21X48	W21X44
13	**Beam**	W31X57	W18X35	W16X36	W18X35
14	**Beam**	W30X90	W18X35	W16X31	W18X35
15	**Beam**	W18X35	W24X55	W18X35	W18X46
16	**Beam**	W18X35	W24X60	W21X50	W24X55
17	**Beam**	W18X46	W21X50	W18X46	W18X46
18	**Beam**	W18X50	W18X46	W18X46	W21X44
19	**Beam**	W18X35	W18X35	W16X31	W16X31
20	**Beam**	W18X35	W18X35	W16X31	W16X31
Total weight (kg)		**65649,00**	**65230,00**	**62312,71**	**61790,16**
Total Beams weight (kg)		**13852,71**	**12954,60**	**10995,08**	**11539,40**
Beams economy weight ratio (%)		**-**	**6,48**	**20,63**	**16,70**

Table 3: Final design for the ten-storey frame using LRFD

The optimum results obtained for designs with rigid and semi-rigid connections considering linear effect behavior of the frames using the NBR 8800 are presented in Table 4 and Table 5.

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W21X50	W24X55	W21X73	W21X68
2	**Column**	W21X50	W21X44	W21X50	W21X50
3	**Column**	W18X35	W12X26	W18X40	W16X26
4	**Column**	W27X84	W30X108	W21X62	W21X62
5	**Column**	W24X55	W24X55	W21X50	W21X44
6	**Column**	W18X46	W18X35	W18X40	W18X40
7	**Beam**	W14X30	W14X30	W14X26	W14X30
Total weight (kg)		**4291,12**	**4253,68**	**3799,14**	**4277,98**
Total Beams weight (kg)		**1715,34**	**1715,34**	**1297,40**	**1715,34**
Beams economy weight ratio (%)		**-**	**0,00**	**24,36**	**0,00**

Table 4: Final design for the three-storey frame using NBR 8800

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W33X424	W33X424	W33X387	W33X387
2	**Column**	W24X76	W33X468	W33X263	W33X291
3	**Column**	W33X387	W18X311	W33X263	W18X291
4	**Column**	W33X387	W33X387	W33X387	W33X387
5	**Column**	W33X141	W18X311	W33X141	W18X175
6	**Column**	W33X141	W33X130	W33X130	W27X368
7	**Column**	W24X492	W18X76	W24X492	W18X143
8	**Column**	W21X201	W27X194	W27X194	W30X326
9	**Column**	W18X65	W18X65	W18X50	W18X65
10	**Column**	W18X65	W18X35	W18X50	W18X65
11	**Beam**	W24X76	W21X57	W21X50	W21X57
12	**Beam**	W21X50	W21X68	W21X48	W21X44
13	**Beam**	W31X57	W18X35	W16X36	W18X35
14	**Beam**	W30X90	W18X35	W16X31	W18X35
15	**Beam**	W18X35	W24X55	W18X35	W18X46
16	**Beam**	W18X35	W24X60	W21X50	W24X55
17	**Beam**	W18X50	W21X50	W18X46	W18X50
18	**Beam**	W18X50	W18X50	W18X50	W21X44
19	**Beam**	W18X35	W18X35	W16X31	W16X31
20	**Beam**	W18X35	W18X35	W16X31	W16X31
Total weight (kg)		**65943,10**	**65533,04**	**63312,92**	**61995,40**
Total Beams weight (kg)		**15052,45**	**13145,60**	**11159,72**	**11879,40**
Beams economy weight ratio (%)		**-**	**6,45**	**25,86**	**21,08**

Table 5: Final design for the ten-storey frame using NBR 8800

The optimum results obtained for designs with rigid and semi-rigid connections considering linear effect behavior of the frames using the CRC are presented in Table 6 and Table 7.

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W21X50	W24X55	W21X73	W21X68
2	**Column**	W21X50	W21X44	W21X50	W21X50
3	**Column**	W18X35	W12X26	W18X40	W16X26
4	**Column**	W27X84	W30X108	W21X62	W21X62
5	**Column**	W24X55	W24X55	W21X50	W21X44
6	**Column**	W18X46	W18X35	W18X40	W18X40
7	**Beam**	W14X26	W14X26	W14X26	W14X26
Total weight (kg)		**4291,12**	**4253,68**	**3799,14**	**4277,98**
Total Beams weight (kg)		**1415,21**	**1415,21**	**1415,21**	**1415,21**
Beams economy weight ratio (%)		**-**	**0,00**	**0,00**	**0,00**

Table 6: Final design for the three-storey frame using CRC

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W33X424	W33X424	W33X387	W33X387
2	**Column**	W24X76	W33X468	W33X263	W33X291
3	**Column**	W33X387	W18X311	W33X263	W18X291
4	**Column**	W33X387	W33X387	W33X387	W33X387
5	**Column**	W33X141	W18X311	W33X141	W18X175
6	**Column**	W33X141	W33X130	W33X130	W27X368
7	**Column**	W24X492	W18X76	W24X492	W18X143
8	**Column**	W21X201	W27X194	W27X194	W30X326
9	**Column**	W18X65	W18X65	W18X50	W18X65
10	**Column**	W18X65	W18X35	W18X50	W18X65
11	**Beam**	W24X76	W24X76	W24X76	W24X76
12	**Beam**	W21X50	W21X50	W21X50	W21X50
13	**Beam**	W31X57	W31X57	W31X57	W31X57
14	**Beam**	W30X90	W30X90	W30X90	W30X90
15	**Beam**	W18X35	W18X35	W18X35	W18X40
16	**Beam**	W18X35	W18X35	W18X35	W18X40
17	**Beam**	W18X50	W18X50	W18X50	W18X50
18	**Beam**	W18X50	W18X50	W18X50	W18X50
19	**Beam**	W18X35	W18X40	W18X35	W18X35
20	**Beam**	W18X35	W18X35	W18X40	W18X35
Total weight (kg)		**65943,10**	**65533,04**	**63312,92**	**61995,40**
Total Beams weight (kg)		**15052,45**	**13145,60**	**13171,72**	**14079,54**
Beams economy weight ratio (%)		**-**	**12,66**	**12,49**	**6,46**

Table 7: Final design for the ten-storey frame using CRC

The optimum results obtained for designs with rigid and semi-rigid connections considering linear effect behavior of the frames using the CRC and LRFD are presented in Table 8 and Table 9.

Group	**Type**	**Rigid**	**T-Stub**	**Top and Seat Angle**	**Double Web Angle**
1	**Column**	W21X50	W24X55	W21X73	W21X68
2	**Column**	W21X50	W21X44	W21X50	W21X50
3	**Column**	W18X35	W12X26	W18X40	W16X26
4	**Column**	W27X84	W30X108	W21X62	W21X62
5	**Column**	W24X55	W24X55	W21X50	W21X44
6	**Column**	W18X46	W18X35	W18X40	W18X40
7	**Beam**	W14X30	W14X30	W14X22	W14X26
Total weight (kg)		**4291,12**	**4253,68**	**3799,28**	**3777,52**
Total Beams weight (kg)		**1715,34**	**1715,34**	**1197,40**	**1415,21**
Beams economy weight ratio (%)		**-**	**0,00**	**30,19**	**17,49**

Table 8: Final design for the three-storey frame using CRC and LRFD

Group	Type	Rigid	T-Stub	Top and Seat Angle	Double Web Angle
1	**Column**	W33X424	W33X424	W33X387	W33X387
2	**Column**	W24X76	W33X468	W33X263	W33X291
3	**Column**	W33X387	W18X311	W33X263	W18X291
4	**Column**	W33X387	W33X387	W33X387	W33X387
5	**Column**	W33X141	W18X311	W33X141	W18X175
6	**Column**	W33X141	W33X130	W33X130	W27X368
7	**Column**	W24X492	W18X76	W24X492	W18X143
8	**Column**	W21X201	W27X194	W27X194	W30X326
9	**Column**	W18X65	W18X65	W18X50	W18X65
10	**Column**	W18X65	W18X35	W18X50	W18X65
11	**Beam**	W24X76	W21X57	W21X50	W21X57
12	**Beam**	W21X50	W21X68	W21X48	W21X44
13	**Beam**	W31X57	W18X35	W16X36	W18X35
14	**Beam**	W30X90	W18X35	W16X31	W18X35
15	**Beam**	W18X35	W24X55	W18X35	W18X46
16	**Beam**	W18X35	W24X60	W21X50	W24X55
17	**Beam**	W18X46	W21X50	W18X46	W18X50
18	**Beam**	W18X50	W18X46	W18X50	W21X44
19	**Beam**	W18X35	W18X35	W16X31	W16X31
20	**Beam**	W18X35	W18X35	W16X31	W16X31
Total weight (kg)		**65649,00**	**65230,00**	**63312,92**	**61995,40**
Total Beams weight (kg)		**13852,71**	**12954,60**	**11159,72**	**11879,40**
Beams economy weight ratio (%)		**-**	**6,48**	**19,44**	**14,24**

Table 9: Final design for the ten-storey frame using CRC and LRFD

It is observed that semi-rigid frames are lighter compared to rigid frames. Table 1 to Table 9 shows that Top and Seat Angle connections give the most economical weight ratio of beams. In these two analyses the size of columns and beams were modified in reason of bending moments. The Brazilian code, NBR 8800 (2008), in this work presents the best results. Althought, The CRC combined with LRFD presents similar results.

These results indicate the importance of realistic connection modeling in the optimum design of steel frames in consideration the curves of the CRC (Column Research Council), the LRFD (American Institute of Steel Construction) and the NBR 8800 (Brazilian Association of Norms Techniques). Failure of accurate modeling of them may yield unsafe designs.

Tables 10 and 11 shows the resume of Beams economy weight ratio (%).

Code	T-Stub	Top and Seat Angle	Double Web Angle
LRFD	0,00	15,39	0,00
NBR 8800	0,00	24,36	0,00
CRC	0,00	0,00	0,00
CRC and LRFD	0,00	30,19	17,49

Table 10: Beams economy weight ratio (%) for the three-storey

Code	T-Stub	Top and Seat Angle	Double Web Angle
LRFD	6,48	20,63	16,70
NBR 8800	6,45	25,86	21,08
CRC	12,66	12,49	6,46
CRC and LRFD	6,48	19,44	14,24

Table 11: Beams economy weight ratio (%) for the ten-storey

5 CONCLUSIONS

In this work, a genetic algorithm based on an optimum design method is presented for linear steel frames with semi-rigid connections. The semi-rigid behavior of beam to column connections is considered in the reliability analysis of steel frames. The numerical examples indicate the importance of the assumption of semi-rigid behavior of connections in the analysis of the system of steel frames. In all cases studied there are substantial differences in the result of reliability analysis between the more realistic semi-rigid connections and the cases in which extreme assumptions of fully-rigid or pinned connections are used.

The use of connection elements in matrix stiffness analyses requires a little modification to the stiffness matrices of the beams and columns in order to establish connection effects. Hence, currently available frame analysis programs can be utilized to analyze semi-rigid frames simply by incorporating this connection elements effects.

As the connections are taken as an independent element, the number of nodes and elements will be increased and larger computer storage is required for the same frame analysis when the connection element effect is used. However, for normal size and routine frames, the storage capacities are no longer a problem for the present computers.

Therefore, the more realistic semi-rigid behavior modeling of connections should be considered in the reliability analysis of steel-framed structures if more reliable results and failure prevent of accurate modeling are desired, even, in consideration the curves of the CRC (Column Research Council), the LRFD (American Institute of Steel Construction) and the NBR 8800 (Brazilian Association of Norms Techniques).

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