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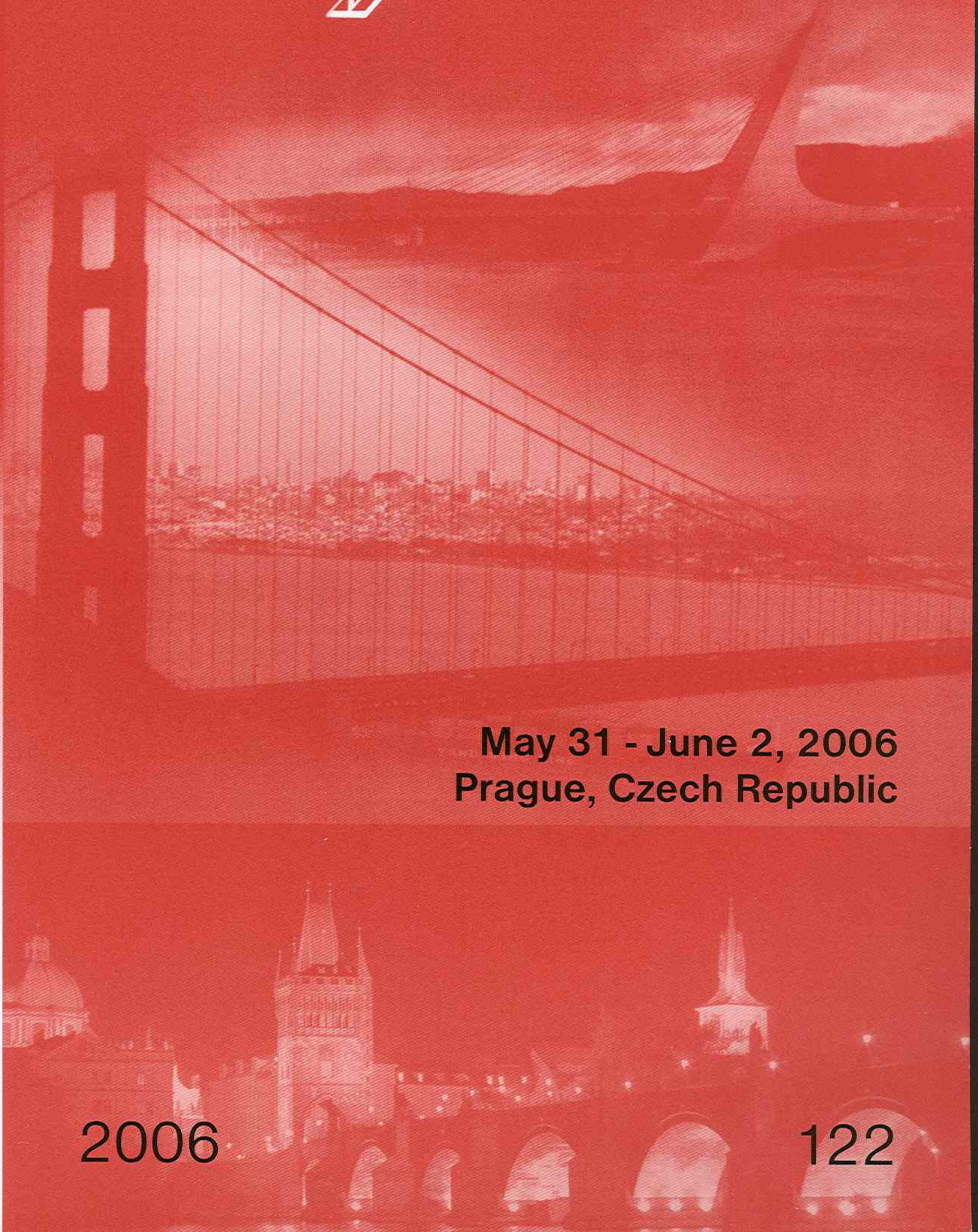

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INFLUENCE OF WEB THICKNESS REDUCTION IN THE SHEAR RESISTANCE OF NON-PRISMATIC TAPERED PLATE GIRDERS

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Abstract

The evaluation of deteriorated members with corrosion, and consequent potential degradation of strength, is found in existing plate girder bridges. This difficult engineer's task is based in a low level of information concerning the shear behaviour of corroded web panels. This insecurity in the evaluation of deterioration members of plate girders bridges must be minimized by using models based on sound theoretical principles, validated by extensive and reliable data.

In this paper are presented the results of degradation of strength, for critical and ultimate shear load, on tapered plate girders with local corrosion (web or flanges), using a nonlinear finite element analysis. In this way, it is also presented the development of a data base with several scenarios of degradation for the creation of predictive models for critical and ultimate shear stress in tapered webs, taking into account different scenarios of thickness reduction. In order to analyze the data generated in the finite element model, Data Mining techniques (e.g., Neural Networks) have been used.

1 INTRODUCTION

Mechanical properties of the traditional bridges materials, such as steel, are readily available, in highly accurate and large volume of statistical data, reducing the uncertainty in the evaluation of its performance. In the same sense, the insecurity on modelling in the field of classical mechanics of materials can also be considered almost irreducible. However, when these structures are affected by corrosion, the uncertainty must be minimized[1].

Until almost 1970, activities of bridge maintenance, repair, rehabilitation, and replacement were based on the need, the experience, and the best existing practice. Bridge management systems became an active field of research when several deteriorated bridges collapsed mainly due to the lack of appropriate maintenance and uncertainty the behaviour of corroded elements[2].

The estimation of load carrying capacity reduction by corrosion contains a relatively high level of uncertainty, and the collection of sufficient field data may take many years[1]. The bridge maintenance costs for bridges will increase quickly, and bridge managers need to use limited budget effectively and plan cost-effective long-term strategies[3,4]. An in-depth study in front of serviceability and ultimate limit states of corroded tapered plate girders is necessary to develop efficient techniques to evaluate the structural integrity and safety, due to the large uncertainties related to the deterioration and maintenance of such structures. Most of the reports are concerned with the causes of corrosion and how to prevent it or how to protect the structures from it, but little is said about the structural safety implications of its presence[5].

There are three basic changes which can occur in a steel bridge due to corrosion: loss of material, reduction of section parameters, and building of corrosion products. Corrosion affects the resistance to shear forces; in this way, buckling capacity of members can be critically affected by the reduction in metal thickness. The most prevalent form of corrosion is a general loss of surface material, affecting the buckling capacity of the web[6].

There is a need for rational criteria which can be used to determine the actual strength of existing tapered plate girders. Therefore, the aim of this study is to investigate the effects of a local thickness reduction, due to corrosion, in tapered web plates, on the elastic critical shear buckling stress and ultimate shear capacity. The analytical tool used in this study is a commercially finite element code (ABAQUS). In order to analyze the data generated in the analytical study, Data Mining techniques (e.g., Neural Networks) have been used[7].

2 PLATE GIRDERS

Plate girders are usually designed when hot rolled beams show insufficient strength or are not economic for design purposes. Depending upon the geometry, the web panel is capable of carrying additional loads considerably in excess of that at which the web starts to buckle, due the postbuckling strength. A plate girder of high strength / weight ratio can be designed taking advantage of this postbuckling strength. More efficient structural elements can often be achieved designing these plate girders as tapered plate girders, usually done by means of a web panel whose depth varies linearly. The use of tapered plate girders is frequently a solution in cases of high moment variation. Designed in accordance with the distribution of bending moments, along the longitudinal direction of the structural systems, tapered web panels with variable inertia provide the required resistance to the girders. Therefore, the use of tapered plate girders leads to a rational and efficient solution[8]. Fig. 1 shows examples of using tapered plate girders in civil engineering systems such as bridges.

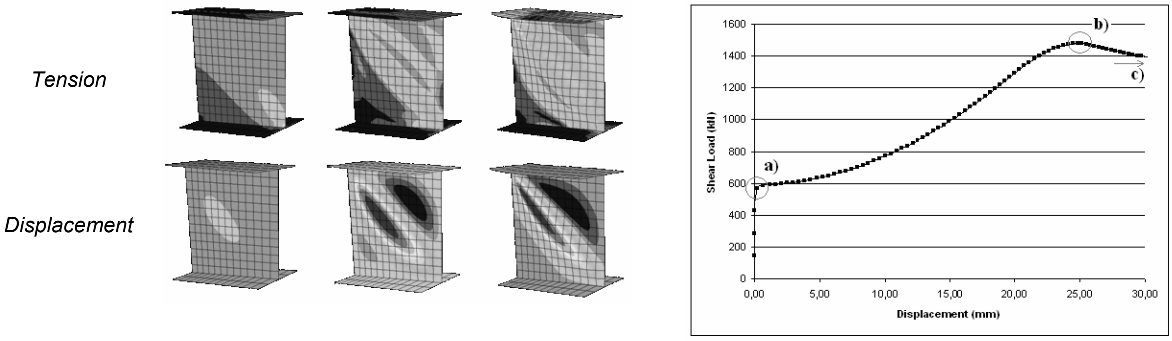
a) b)

Figure 1 Tapered Plate Girder Bridge. a) Quai-Brücke Bridge, Zürich. b) Grenelle Bridge, Paris.[8]

3 SHEAR BEHAVIOUR OF A PLATE GIRDER

The usual models to evaluate the shear capacity of plate girders are based on the diagonal tension field theory, interpreted by three resistant mechanisms: the first mechanism, the elastic shear buckling strength of the web plate (see Fig. 2a); the second one, the post-buckling strength of the web plate, interpreted by the development of the tension field (see Fig. 2b); the last one, the sway failure mechanism, which implies that the web panel reaches failure when plastic hinges are developed in the flanges (see Fig. 2c).

Out-of-plane displacements of web panels are measured at each increment in the central node of the web panel, resulting in a plot shown in Fig. 2d, which clearly exhibits a bifurcation buckling point.



a) *b)* *c)* *d) Curve shear load – perpendicular web displacement*

Figure 2 Shear behaviour of a typical web panel.

4 NUMERICAL MODEL

Corroded steel tapered plate structures in front of ultimate and serviceability limit states requires in-depth study of possible instability phenomena. The determination of the elastic critical shear buckling stress and ultimate shear capacity should take into account several structures phenomena that are difficult to quantify and differentiate one from another as they occur simultaneously, and can appear even at low load levels. These are web buckling and yielding of the steel. It is therefore necessary to study those phenomena using general methods of analysis that provide a realistic approach to the main aspects of their non-linear behaviour. These aspects include, first, the influence of the second-order effects on global equilibrium of the structural element (geometric non-linearity) and second, the complexities derived from the real behaviour of the material (material non-linearity)[8].

Nonlinear analyses have been conducted in a three-dimensional finite element model of transversely stiffened corroded tapered plate girders, by thickness reduction, subjected to pure shear. To obtain the buckling predictions with ABAQUS, a BUCKLE step is performed. Following the eigenvalue buckling analysis, the STATIC, RIKS procedure is used to perform the postbuckling analyses. Nine-node shell elements (S9R5) are used to discretize the geometry of the tapered pieces, in a 13x13 mesh in the web panel and 13x4 in the flanges. To perform the nonlinear analysis, a relatively small initial deformation (h/200000) must be applied to initiate buckling. The Kirchhoff theory for thin plates is assumed in the present study. In order to reduce running time, the reduced integration algorithm is used. The hypothesis of large displacements and small strains is considered. Large displacements were incorporated, updating repeatedly the geometry of the structure after each load increment to assure global equilibrium over the deformed configuration. Steel properties are defined as a biaxial isotropic material model combined with the von Mises yield surface. The yielding surface may move as stiff solid. The stress-strain relationship is based on the characteristic uniaxial σ-ε diagram of the steel with elasto-plastic behaviour.

The geometric dimensions of the model are defined in Fig. 3, where h_1 is the higher depth of the web panel, and h_0 the lower; a is the transverse stiffener spacing; t_w is the thickness of the web panel; t_f is the thickness of the flange; b_f is the width of the flange; and ϕ is the slope of the bottom flange. The standard parameters of a tapered plate girder are: α is the aspect ratio of the web, defined by the ratio between the transverse stiffener spacing and the greatest depth of the web ($\alpha = a / h1$); η is the flange width to the maximum web depth ratio ($\eta = b_f / h1$); λ_f is the flange slenderness ($\lambda_f = b_f / t_f$); and $tg\phi$.

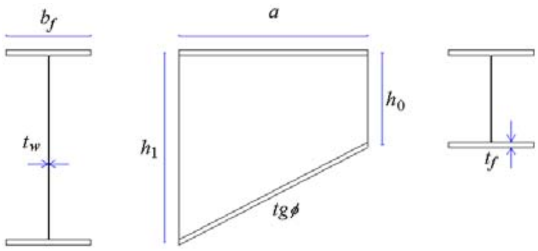


Figure 3 Geometric parameters of a tapered plate girder.

5 RESULTS

By combining information on the rate and location of an eventual corrosion in web and flange panels, it is possible to predict elastic critical shear buckling stress and ultimate shear stress. In this sense, for a random steel plate girder, with the geometric proprieties shown in Table 1, nonlinear analyses have been conducted with the objective of detect the critical zones of a web and flange panels, and what strength reduction may we possibly expect.

In this study was considered an S355, with the next proprieties: Young's modulus of 210 MPa; Poisson's ratio of 0.3; yield stress of 355 MPa; and ultimate stress of 510 MPa.

Table 1 Geometric properties

α	*tg&*	h_1 (mm)	t_w (mm)	b_f (mm)	t_f (mm)	Critical Load (kN)	Ultimate Load (kN)
1,00	0,30	2000	8	900	24	635,0	1261,7

To evaluate the effects of corrosion on structural performance, the various regions where corrosion occurs can be evaluated in terms of the net remaining area[6]. In this way, corrosion was introduced into the model by reducing the thickness of a different single corroded area, and then in different sets. For the web panel (see Table 2), the affected areas had t_w = 7mm and, for the flanges (see Table 3), the corroded area had t_f = 15mm.

Table 2 Results for local thickness reduction on the web panel

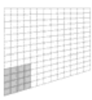
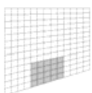
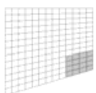
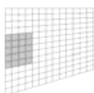
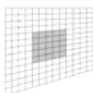
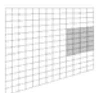
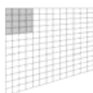
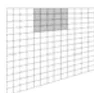
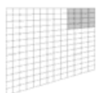
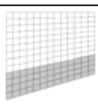
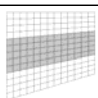
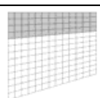
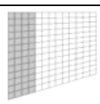
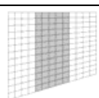
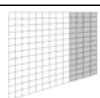
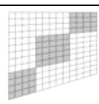
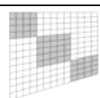
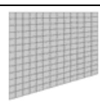
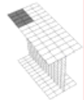
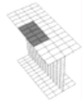
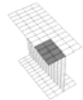
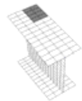
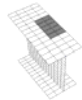
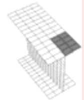
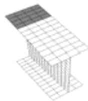
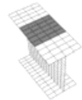
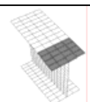
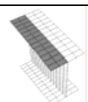
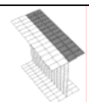
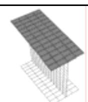
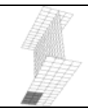
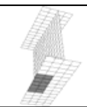
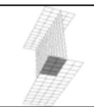
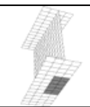
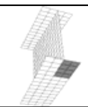
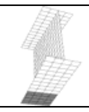
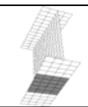
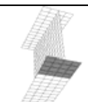
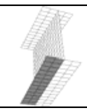
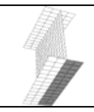
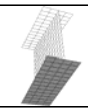
Model									
Critical Load (kN)	639,4	618,4	612,9	610,7	558,1	612,2	577,1	597,2	635,8
Ultimate Load (kN)	1261,0	1256,8	1233,6	1249,1	1215,8	1245,1	1097,8	1235,6	1260,5
Model									
Critical Load (kN)	599,8	520,3	548,8	557,1	512,8	588,9	564,8	491,1	439,2
Ultimate Load (kN)	1230,0	1191,7	1075,3	1084,3	1191,5	1217,5	1216,2	1038,7	996,3

Table 3 Results for local thickness reduction on the flanges

Model								
Critical Load (kN)	631,7	626,6	628,3	631,7	626,6	628,3	626,7	615,9
Ultimate Load (kN)	1258,0	1257,2	1258,7	1256,9	1257,4	1258,1	1253,4	1252,6
Model								
Critical Load (kN)	618,9	618,8	618,8	591,7	635,7	638,6	639,4	635,7
Ultimate Load (kN)	1254,5	1253,1	1251,7	1233,1	1260,8	1261,0	1258,4	1260,8
Model								
Critical Load (kN)	638,6	639,4	636,3	641,6	642,8	642,4	642,4	648,9
Ultimate Load (kN)	1260,9	1258,1	1260,8	1261,1	1256,1	1258,2	1257,9	1255,5

Resist to shear force and maintain relative distance between the bottom and top flanges are the primary functions of the web plate in a plate girder. The loss in web material will reduce shear capacity due to both section loss and geometric buckling[6].

The results obtained show that there are different consequences upon shear strength for a small thickness reduction of the web panel, depending on the location: for the elastic critical shear buckling load, the central portion of the panel is the most influent; for the ultimate load, the reduction of thickness on the left top corner is the most relevant.

The results presented in Table 3 show an almost despicable reduction on strength and in the behaviour on shear of tapered plate with flanges highly corroded. Generally, corrosion is more prejudicial in the top flange, and in front of elastic critical shear buckling stress. However, flanges carry on the bending stresses principally, and the affection of corrosion should be study on this type of loads.

6 DATA MINING

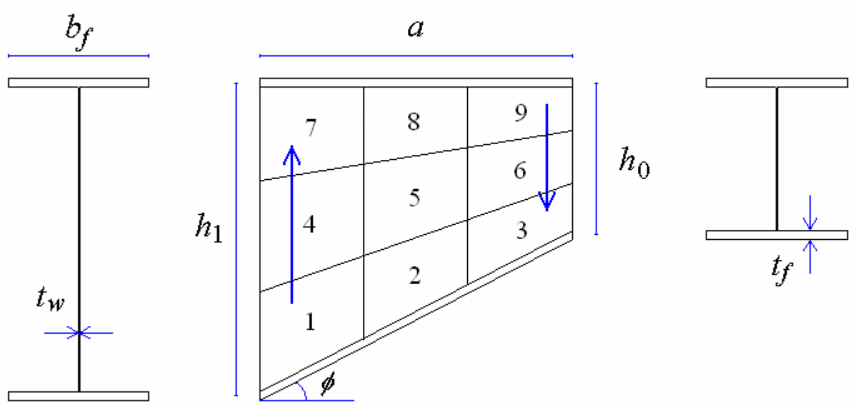
The application of Data Mining (DM) techniques to analyze civil engineering data has gained an increasing interest in recent years, due to intrinsic characteristics such as ability to deal with non-linear relationships. DM has it roots in statistics, probability theory and machine learning. One of the underlying principles of knowledge discovery in data is to promote the process of building data-driven expert systems as an extension of the more traditional Artificial Intelligence expert systems approach. The idea is now that experts can learn from new findings in the data as well.

Using the finite element model presented, it was created a large and extensive database with 5670 scenarios of degradation, in web panels with h_1 = 2000 mm (see some examples in Table 4 and Figure 4).

This data, analyzed with Data Mining techniques, will be certainty an important tool in the inspection and assessment of steel girder bridges, especially on the evaluation of corroded tapered plate girders bridges.

Table 4 Data base structure

α	λ_f	η	tg&	b_f (mm)	t_f (mm)	f_c (kN)	f_u (kN)	z1 (mm)	z2 (mm)	z3 (mm)	z4 (mm)	z5 (mm)	z6 (mm)	z7 (mm)	z8 (mm)	z9 (mm)
1.0	45.00	0.45	0.20	900	20.0	612.3	1336.7	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1.0	45.00	0.45	0.20	900	20.0	443.3	1073.4	7.0	7.0	7.0	8.0	7.0	8.0	7.0	7.0	7.0
1.0	45.00	0.45	0.20	900	20.0	566.2	1294.8	8.0	8.0	7.0	7.0	8.0	8.0	8.0	8.0	7.0
1.0	45.00	0.45	0.20	900	20.0	436.5	1108.2	7.0	7.0	8.0	7.0	8.0	7.0	7.0	7.0	8.0
1.0	45.00	0.45	0.20	900	20.0	438.2	1083.9	8.0	7.0	8.0	7.0	7.0	8.0	7.0	7.0	8.0
1.0	45.00	0.45	0.20	900	20.0	447.0	1074.0	7.0	8.0	7.0	7.0	7.0	7.0	7.0	8.0	7.0
1.0	45.00	0.45	0.20	900	20.0	508.2	1112.2	7.0	8.0	7.0	7.0	8.0	7.0	7.0	8.0	8.0
1.0	45.00	0.45	0.20	900	20.0	520.1	1132.6	8.0	7.0	8.0	8.0	8.0	8.0	7.0	7.0	8.0
1.0	28.13	0.45	0.60	900	32.0	515.8	776.3	7.2	7.2	7.2	7.2	7.2	7.2	8.0	7.2	7.2
1.0	28.13	0.45	0.60	900	32.0	449.0	734.7	6.8	6.8	6.8	6.8	6.8	6.8	8.0	6.8	6.8
1.0	12.50	0.20	0.10	400	32.0	207.7	805.2	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
1.0	12.50	0.20	0.10	400	32.0	76.7	593.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
1.0	60.00	0.25	0.20	500	8.3	464.1	1195.5	7.6	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1.0	60.00	0.25	0.20	500	8.3	465.1	1195.5	7.2	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1.0	60.00	0.25	0.20	500	8.3	466.3	1195.6	6.8	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1.5	56.25	0.45	0.50	900	16.0	433.7	424.5	8.0	8.0	8.0	8.0	8.0	7.0	8.0	8.0	8.0
1.5	10.00	0.20	0.00	400	40.0	463.9	1175.4	8.0	8.0	8.0	8.0	8.0	8.0	7.0	8.0	8.0
1.5	25.00	0.20	0.00	400	16.0	399.3	1092.2	8.0	8.0	8.0	8.0	8.0	8.0	7.0	8.0	8.0
0.5	56.25	0.45	0.20	900	16.0	1114.7	1821.6	8.0	8.0	7.0	8.0	8.0	7.0	8.0	8.0	7.0
0.5	56.25	0.45	0.20	900	16.0	1089.4	1814.0	7.0	8.0	8.0	8.0	7.0	8.0	8.0	8.0	7.0
0.5	10.00	0.20	0.30	400	40.0	978.8	1538.6	8.0	8.0	7.0	8.0	7.0	8.0	7.0	8.0	8.0
0.5	56.25	0.45	0.20	900	16.0	833.3	1494.2	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0



$$\lambda_f = \frac{b_f}{t_f}$$

$$\eta = \frac{b_f}{h_1}$$

$$\alpha = \frac{a}{h_1}$$

Figure 4 Geometric parameters presented on the database.

7 CONCLUSIONS

The results obtained show that there are different consequences upon the shear strength of a corroded web panel, depending on the location of the corrosion: for the elastic critical shear buckling load, the central portion of the panel is the most influent; for the ultimate load, the reduction of thickness on the left top corner is the most relevant. These results shows also that exists a despicable reduction of the shear strength of a tapered web panel with flanges highly corroded. However, flanges carry on the bending stresses principally, and the affection of corrosion should be study on this type of loads.

Using a validated finite element method, it is possible to create a large and extensive database, with various scenarios of degradation. This data, analyzed with Data Mining techniques, is a contribution to the development of new knowledge about the shear behaviour of corroded web panels in plate girders.

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