Proceedings of the International Conference on Structural Health Monitoring of Intelligent Infrastructure
Porto, Portugal, 30 June - 2 July 2021
ISSN 2564-3738

Obtaining of variable geometry beam models for steel beams with corrosion

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ABSTRACT: The most common pathology that causes the main maintenance and durability problems in steel structures is corrosion, since it causes the loss of material from the beams that form the structure, diminishing its properties and therefore the general resistance of the structure. After cleaning the corrosion on a beam, its surface becomes very irregular and it is very difficult to measure and extract the geometry of these shapes and surfaces manually. To this end, laser scanning and its subsequent point cloud is a promising method. The objective of this work is to show how obtaining beam models with extruded slices of one beam affected by corrosion for subsequent analysis structural from the laser scanning. The proposed steps were applied and validated in laboratory study cases.

KEY WORDS: Diagnostics, Health management, Structural Health Monitoring, Corroded beam.

1 INTRODUCTION

The durability of a steel structure depends totally on its maintenance, whose main problem is the pathologies suffered by the structure; being corrosion the most common pathology. Corrosion is a very widespread problem at a global level and, in fact, at a European level it is estimated that it represents 3.8% of GDP [1].

In order to recover a structure that has suffered corrosion, it is necessary to apply different techniques to be able to eliminate this corrosion. Depending on the type of corrosion suffered by the beams, some cleaning techniques are used or others so that the corroded surface is clean for analysis. In general, this surface is very difficult to measure as it is usually very irregular after cleaning.

After manufacture, the beams must have nominal dimensions that are specified in the respective dimensional and shape standards for each type of beam. These nominal dimensions have tolerances that are also included in standards such as, for example, UNE-EN 10034:1994 [2] and UNE-EN 10279:2001 [3], which indicate the dimensional and shape tolerances of I-beam and H-beam of hot-rolled steel and U-beam hot-rolled steel respectively. Due to these tolerances, the nominal cross-sectional dimensions of the beams may differ; in addition to this possible variation, they may also vary due to loss of material caused by corrosion or human action. The most critical situation for the beams of a structure and that must always be evaluated is when the combination of the minimum tolerances in the beams and their loss of mass due to corrosion occurs.

Currently, to extract the geometry of any type of scenario in general, one of the most widely used methods is laser scanning. This is a very promising method and in the specific case of steel structures it has been used in several works to obtain the 3D models of these structures with which to carry out simulation by the finite element method (FEM). One of the most important of these works is that carried out by Conde et al.[4], in which the geometry of electricity transmission towers is obtained using TLS (Terrestrial Laser Scanner) to carry out 3D modelling and structural FEM analysis. Along the same lines as this work is that carried out by Cabaleiro et al. [5], in which TLS is also used, but in this case for an industrial metal frame.

TLS technology has the advantage of taking measurements at distances of more than 100 meters but with the limitation of having an accuracy around ± 2 mm, so it is a suitable technique for extracting general measurements of the structures but not for obtaining precise measurements of the irregular surface and net section of their beams. In this type of case, it is more suitable to use high precision laser technology as it has an accuracy of less than 1 mm. Laser arms are an example of this technology that has already been used in some works to analyse the deformation of steel beams, such as the one carried out by Cabaleiro et al. [6] in which the deformation produced by loads on beams of less than 1 m was analysed. This same technique has also been used by Fernandez et al. [7], Wang et al. [8] and Kashani et al. [9] to analyse the loss of mass in steel bars due to corrosion. Of considerable importance are also the works in which laser technology is employed by Hain et al. [10] and Xiao et al. [11], in which the loss of material in corroded steel beams in bridges is evaluated and high-performance steel (HPS) samples are extracted to investigate the impact of corrosion, respectively.

The objective of this work is to show, by obtaining point clouds generated from laser scanning, how to model corrosion-affected beams with extruded cuts for subsequent structural analysis and health management more efficiently than current techniques based on beam rendering. This work also aims to obtain a beam diagnosis of the mass lost to corrosion and to monitor the structural health of the structure.

2 PERFORMED STEP

The following steps are done to obtaining the beam model:

a) Scanning of the beams.

b) Point cloud cleaning. Cleaning the point cloud of each beam from noise or scanned parts that do not belong to the beam.
c) Slicing of the beam (Figure 1). The cloud of points is divided into cuts along the longitudinal direction of the beam.
d) Contour drawing from the slices of the point cloud
e) Extrusion of each slice from the contour drawing and assembling of all the slices to obtain the beam.
f) Calculation of the beam. Finally, the structural analysis of the beam is done.

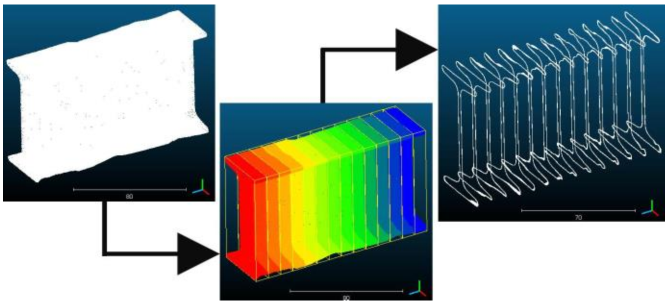

Figure 1. Slicing of the beam.

3 APPLIED MATERIALS AND EQUIPMENT

The proposed steps were applied on a laboratory case study. One beam with lack material and corrosion was used (Figure 2). An IPN80 which presents an advanced state of corrosion, as well as loss of material by human actions was tested. For the laser scanning, a 6-axis FARO S Quantum arm with a 0.048 mm contact measurement precision and 0.025 mm accuracy in the laser source, was used. For the treatment of the point cloud obtained, the software CloudCompare will be used and for the resistant analysis Solidwork will be used.

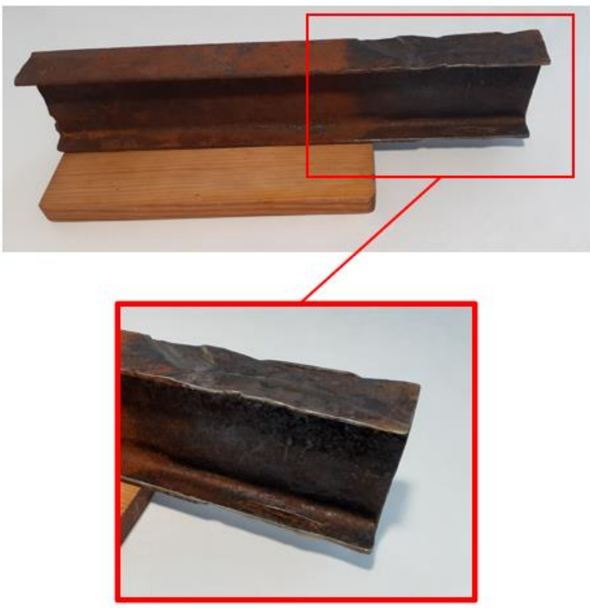

Figure 2. Photos of the beam to be tested in the laboratory.

4 TESTS PERFORMED

Two models are obtained from the point clouds: one using extruded slices and the other by rendering the point cloud. Both models must be equivalent in terms of strength calculation, so tests are carried out which consist of subjecting the two models to bending tests (Figure 3). The test consists of a cantilever beam, embedding the end most affected by corrosion and applying a point load at the opposite end.

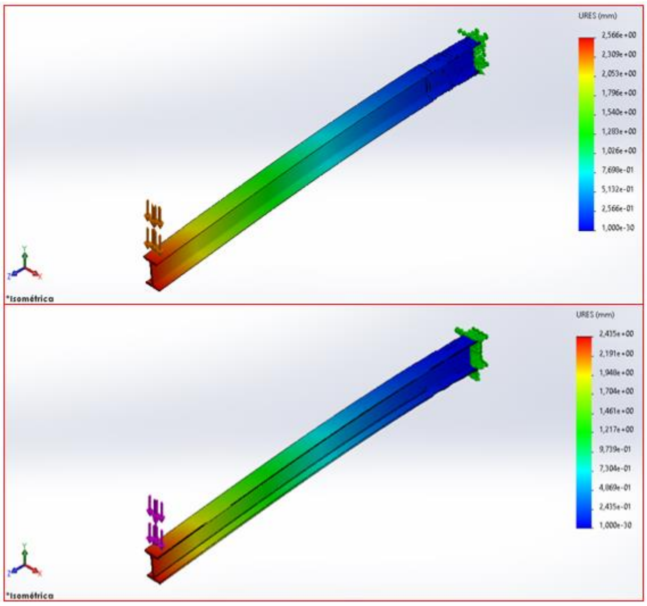

Figure 3. Calculation of the beam by extruded slices and rendering.

The deformation, the calculation time and the occupied memory space are the main results that will be compared from the tests of both models. Furthermore, to check that the corrosion presented by the beam is really significant, the deformation results of the corroded beam are also compared with the deformation presented by the non-corroding beam under the same loads.
It should be noted that the first model, the extruded slice model, is obtained from the extrusion of each of the contour drawing that are made from the slices obtained when the beam is sliced along the longitudinal direction of the beam. Taking into account the thickness of the slices, each slice is extruded to the same size and all are assembling to obtain the model of the complete beam. It is also important to mention that the contour drawing of each slice represents the most unfavourable section of the beam.
In the case of the second model, the rendering model, a previous analysis is carried out to determine what the minimum size is appropriate for the rendering and meshing, in order to guarantee an adequate level of rendering and subsequent meshing in the FEM analysis calculations.

5 ACHIEVED RESULTS AND DISCUSSION

The first thing calculated was what is the minimum model representation size that provides a final model for proper calculation (Figure 4). For this purpose, the surface was rendered with 10,000, 5,000, 1,000, 500 and 100 elements.

The model obtained with this rendering was calculated by meshing each model with a mesh quality in all cases higher than 0.65. As can be seen in the graph (Figure 5), the deformation values obtained in the cases from 10,000 to 500 are very similar, while from 500 to 100 elements there is already an important variation in the deformation, so it can be concluded that a rendering with 1,000 elements would already guarantee with a safety margin of 2 an adequate value for the rendering of these beams, while 500 or less might not be adequate anymore.

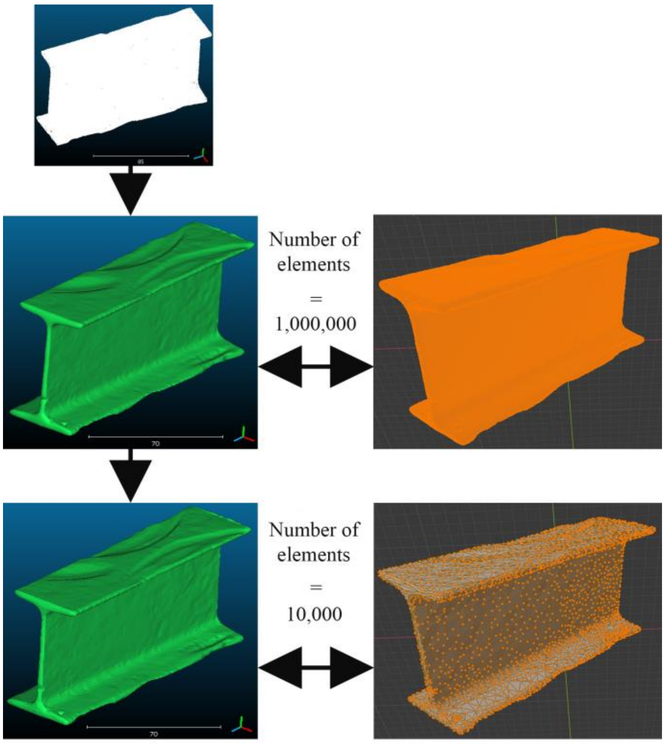

Figure 4. Reduction of the number of elements in the model to achieve the minimum rendering size that provides a final model for proper calculation.

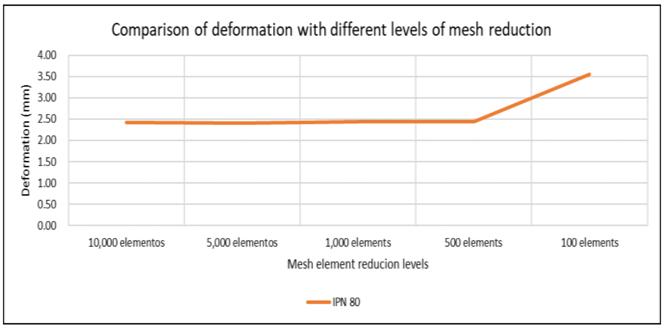

Figure 5. Deformation graph at beam end according to number of rendering elements.

Once defined that 1,000 rendering elements are enough, it is checked what minimum mesh size is necessary to have an acceptable mesh quality and result. Different mesh sizes are tested and finally a mesh with a quality higher than 0.7 is defined as adequate. Since from there we can increase the number of elements, but the quality of the mesh does not improve substantially. As we can see that according to Figure 6 with a mesh of 177,000 elements for the IPN 80 we would already obtain a mesh with quality higher than 0.7.

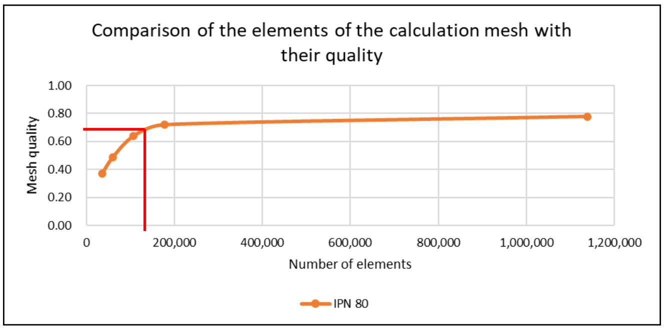

Figure 6. Quality of the mesh depending on the number of elements in the mesh.

Using a pre-rendering of 1,000 elements and a mesh for the tetrahedral calculation with a quality of 0.7 the results obtained were those of Table 1.

Table 1. Deformation results in millimetres from FEM tests performed.

Beam type	Non-corroded	Extruded slices	Rendering
IPN 80	2.19	2.566	2.435

In the data obtained, it could be clearly observed that the corrosion had an important incidence with respect to the deformation reached by the beam, that is to say, the corrosion has affected the resistant capacity of the beam. In fact, the deformation of the beam has increased an average of 14% due to the corrosion. On the other hand, it can be seen that the differences obtained between the results found with the proposed methodology and the rendering differences are close to 5.3% error, so the proposed model of extruded slices is suitable for the calculation.
But instead, the differences in calculation times and space occupied is really very important. The calculation time for the rendered model was 14 seconds while for the model extruded slices it was 8 seconds. In the case of the occupied space, in the rendered model it was 108 MB, while for the extruded slices it was 69.4 MB. In fact, on average the calculation time needed for the rendered model was 1.75 times higher than for extruded slices, while the space occupied by the calculation as rendered was on average 1.55 times higher than for extruded slices.
Although the results of the extruded slice model are better than those of the rendering, the improvement offered by this method has not been sufficiently relevant. For this reason, and using several steps of the methodology of extruded slices, a new model of beam elements is proposed. The step in common with the extruded slice model and the beam element model is to obtain the contour drawing of each slice. In the case of beam elements, instead of being extruded, their geometrical properties are calculated for that section. This can be done automatically with the algorithm proposed by Cabaleiro et al. [12].

Once the properties have been obtained, they are saved in an Excel file in which a macro is generated so that, automatically and independently of the number of slices from which the properties are obtained, a script in .js format is generated and executed in ANSYS to generate the beam element model.

The two previous steps (calculating the properties and modelling the model of beam elements) are done quickly due to the automation of the process, as explained above. Once the beam element model is obtained, the FEM analysis is performed with the same characteristics as in the case of rendering and extruded slices.

The results of the FEM analysis of the beam element model in ANSYS are as follows: a deformation of 2.482 millimetres, a calculation time of 0.2 seconds and a storage size of 9.19 MB. The difference in the deformation between the rendering and the beam elements is less than 2%, the calculation time is 70 times less and the storage size is approximately 11.75 times less. Therefore, the beam model is the optimum of the three models, so we must go deeper into this method to obtain more results as these are preliminary.

It should be taken into account that when modelling the beams on the basis of the actual measurements of the profile, possible initial differences in the measurements of the profiles due to the manufacturing process are also considered (even if the measurements are within the tolerances of the standards). In fact, for example, for an IPE 220 beam 1,000 mm long embedded at one end and with a 10 kN load at the other (Figure 7), the difference in deformation for the case of using the maximum measurements allowed in its section is 1.18 mm, while with the minimum measurements it is 0.81 mm; in other words, a difference of 45%. Therefore, for the analysis of existing structures it is very important to use the real measurements of the profiles and not the theoretical ones according to the standards.

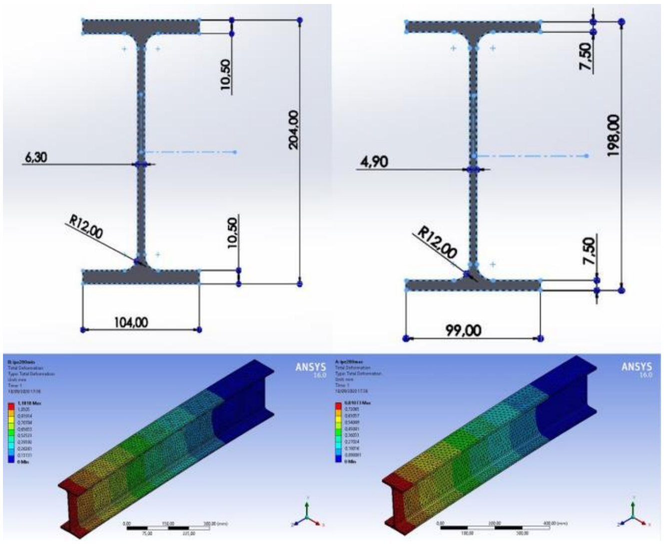

Figure 7. Calculation of an IPE 200 with the possible maximum and minimum measurements according to the standards due to its manufacturing process.

6 CONCLUSIONS

Based on the results found, it can be said that this work shows how obtaining from the laser scanning beam models with extruded slices and beam elements of steel beam is suitable for structural analysis, achieving final results of equal precision with respect to traditional methodologies based on rendering and solid meshes, but being faster and occupying at least storage memory. Despite the fact that both methods present good results, the beam element model presents much better results, so it is the best option.

Future work should dedicate to automate the methodology of the beam element model, carry out more test and apply it in more complex structures made up several beams. Also, this methodology should be tested and validated to cases of real steel or iron structures which present corrosion in their bars.

ACKNOWLEDGMENTS

This work has been partially supported by the Spanish Ministry of Science, Innovation and Universities through the project Ref. RTI2018-095893-B-C21, and the SIRMA project, which is co-financed by the INTERREG Atlantic Area Programme through the European Regional Development Fund (ERDF) with application code: EAPA_826/2018.

REFERENCES

[1] E. Bowman, International Measures of Prevention, Application, and Economics of Corrosion Technologies Study, NACE International, Houston, USA, 2016.

[2] UNE-EN 10034:1994 – Perfiles I y H de acero estructural. Tolerancias dimensionales y de forma.

[3] UNE-EN 10279:2001 – Perfiles en U de acero laminado en caliente. Tolerancias dimensionales, de la forma y de la masa.

[4] B. Conde, A. Villarino, M. Cabaleiro and D. Gonzalez-Aguilera, Geometrical Issues on the Structural Analysis of Transmission Electricity Towers Thanks to Laser Scanning Technology and Finite Element Method,Remote Sensing, 7, 9, 11551-11569, 2016.

[5] M. Cabaleiro, B. Riveiro, P. Arias, J. C. Caamaño, and J. A. Vilán, Automatic 3D modelling of metal frame connections from LiDAR data for structural engineering purposes, ISPRS Journal of Photogrammetry and Remote Sensing, 96, 47-56, 2014.

[6] M. Cabaleiro, B. Riveiro, B.Conde and A. Sanchez, A case study of measurements of deformations due to different loads in pieces less than 1 meter from lidar data, Measurement, 151, 2020.

[7] I. Fernandez, J. M. Bairán, and A. R. Marí, 3D FEM model development from 3D optical measurement technique applied to corroded steel bars, Construction and Building Materials,124, 519-532, 2016.

[8] X. G. Wang, W. P. Zhang, X. L. Gu and H. C. Dai, Determination of residual cross-sectional areas of corroded bars in reinforced concrete structures using easy-to-measure variables, Construction and Building Materials, 38, 846-853, 2013.

[9] M. M. Kashani, A. J. Crewe and N. A. Alexander, Use of a 3D optical measurement technique for stochastic corrosion pattern analysis of reinforcing bars subjected to accelerated corrosion, Corrosion Science, 73, 208-221, 2013.

[10] A. Hain, A. E. Zaghi, A. Kamali, R. P. Zaffetti, B. Overturf and F. E. Pereira, Applicability of 3-D Scanning Technology for Section Loss Assessment in Corroded Steel Beams, Transportation Research Record, 2673, 3, 271-280, 2019.

[11] L. F. Xiao, J. X. Peng, J. R. Zhang and C. S. Cai, Mechanical properties of corroded high performance steel specimens based on 3D scanning, Advanced Steel Construction, 15, 2, 129-136, 2019.

[12] M. Cabaleiro, R. Lindenbergh, W. F. Gard, P. Arias and J. W. G. van de Kuilen, Algorithm for automatic detection and analysis of cracks in timber beams from LiDAR data, Construction and Building Materials, 130, 41-53, 2017.