GOTHIC TIE ROD ANCHOR DESIGN: REPRESENTATION AND STRUCTURAL EFFICIENCY OF NORTHERN EUROPEAN ELEMENTS

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ABSTRACT:

This paper aims to provide knowledge and help discover types of Baltic buildings, by recognizing and understanding their structural elements. The presented approach allows generating a recognizable spatial configuration of the structural ornamental elements that are traces of the past and re-presentation of the same line today. Tie rod anchors contemporaneously have a historical, aesthetic, formal and structural role. Their structural behavior is analyzed producing digital models. Results show the high quality of the element Gothic design, of essential historic importance, and their more structural efficiency than traditional Italian bar shaped tie rod ends. It is shown how, maintaining their formal, historical, representative value, the tie rod anchor structural functionality is increased due to the particular northern European local craft manufacture. The results presented in this paper are based on work developed with Giuseppe Faella, Full Professor of Structural Engineering at the Second University of Naples.

1. INTRODUCTION

Tallinn, European Capital of Culture in 2011, has planned manifestations on the 'Stories of the Seashore' i.e. on the legends inspired by Estonian sailors. In the European manifestation that began in 1985, Tallinn and Turku in Finland were the protagonists of a movement that attracted a lot of important names in international culture, showing creativity that can be seen in the city alleyways in the best possible way. The excellence of this place inspired the study to focus on the journey of knowledge to preserve the historical and formal features of northern European design. The development of new conservation techniques is accompanied by the discovery of new mechanical and physical properties of materials that are more hardwearing and durable than traditional materials. The objective of the research is to demonstrate how the use of traditional materials such as wrought iron, typical of Northern Europe, continues to provide an efficient response to the behavior of the structure. It preserves functionality and, at the same time, respects the interesting and peculiar aesthetic, historical and formal tie rod anchors, helped by the particular form of decorative design capable of performing the distribution function of forces. The tie rod anchor has marked the history of this town and, over time, has become a distinguishing feature and attractor for these places. This paper relates to the study on the tie rod anchor efficiency in masonry structure, while anchor plate modelling experimentation on the northern European (Stockholm) has been progressing, for a long time, at the BENECON laboratory of the Second University of Naples, School of Architecture.

To preserve the morphological, aesthetic and historical aspects of design, assessment of the increase in the efficiency of the element anchor plate, shows that the Gothic, symbolism characteristic involved in the breakdown of the pulling force of the anchor plate on the wall is more efficient than the traditional form of European bar shaped tie rod end. Art design in northern Europe resumes the ancient craft. There, this term covers all fields of human action (architecture, urban planning, sculpture). In Italy this term is only used in the industrial field. During the Industrial Revolution in 1700, high philosophy became positive empirical philosophy. A practical turn that took place in the political culture led to capitalism, liberalism and, on the material level to the invention of machines that meant that everything that until then had been made by hand could now be produced by machines. The result was the production of large quantities at the right price.

After there was a return to the Middle Ages with arts and crafts whose motto was "the joy in the labour", which rejected contemporary fashion and produced a losing fashion against the business activity. Morris himself, some years later, realized that one should not hinder the industrial machine but should qualify the new product on the basis of an aesthetic tradition rather than copy the recent past. This did not constitute a revival of the Gothic itself, but many artists and sculptors were dedicated to the arts applied to the art of design manufacturing. This is the inspiration for this research. The quality of northern European craftwork steeped in culture of design quality, together with structural efficiency, are aspects that empirically found a response to the excellent speeches held in small towns where they were not fascinated by the "fast industrial design machines" but have kept the traces of art rules and made this the driver of local marketing.


(a)


(b)

Figure 1: Tallinn: retrofitted building in old town (a), retrofitted sacred building in old town (b)

Figure 2: Tallinn: wall of the old town


(a)


(b)

Figure 4: Tallinn: building in old town (a), tie rod anchor (b)

2. BALTIC ARCHITECTURE AND STRUCTURAL DESIGN OF GOTHIC BUILDING

A particular meaning of Gothic or Gothic-German architecture is one that developed in Northern Europe between the thirteenth and fifteenth century. The countries involved in this type of medieval architecture were in the north of the Holy Roman Empire, Teutonic settlements and citizens of territories of the Hanseatic League. The characteristic of the buildings in Northern Europe was the use of clay, different from that adopted by French Gothic. In addition to church buildings and the Church of St. Mary Lübeck in Germany, with its slender forms that was considered a landmark for several centuries, in northern Europe found space on buildings with dark red brick facades, fancily decorated with figures abstract geometric inserts and plaster to create a clear contrast. Facades are like business cards for the observer that cannot imagine the interior of the building but is captured by those particular identification details.

Heinrich Brunsberg, a famous Baltic architect developed a virtuous theme of brick decoration between the fourteenth and fifteenth century. The design represented by anchor plate being studied, recalls the issue of quality at a fair price compared to that notion that objects should only serve their function. These are not industrial design objects, but objects that are of a different identity depending on their location.


(a)

(b)

Figure 3: Stockholm: Stortorget sq. in Gamla Stan district (a), building façade (b)

3. VIEW OF THE CITY OF TALLINN BY RECOGNISING TIE ROD ANCHORS AND STRUCTURAL ELEMENTS. ANALYSIS METHODS

Obtaining information on site, from a visual to photographic analysis and via metric relief up to investigation with non-invasive instruments, are part of a process phase that can be defined by the concept of knowledge. Being kidnapped by feelings that an urban environment like that of Northern Europe can result in visiting those places, is something to be reckoned with in the recognition of characteristics territorial values of every places. The Multicriteri@ approach used for the preparation of this paper is something that goes beyond simple information that represents a network of true statements analyzed by different professionals: a multi-disciplinary approach with lists of information and links that result from the critical analysis of relationships between them. “Knowledge management" of the building elements, the object of this research, meant primarily representing and providing a supporting container, knowledge of the characteristics of the aesthetic, formal elements. This representation has meant that geometric elements of reality could be transmitted and could be studied on computer media in

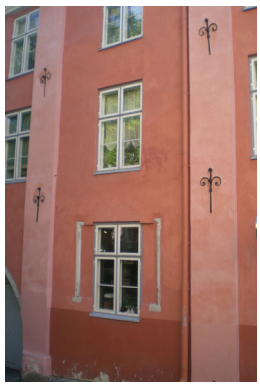

(a)

(b)

Figure 5: Tallinn: Building in old town (a), building façade with Gothic tie rod anchor (b)

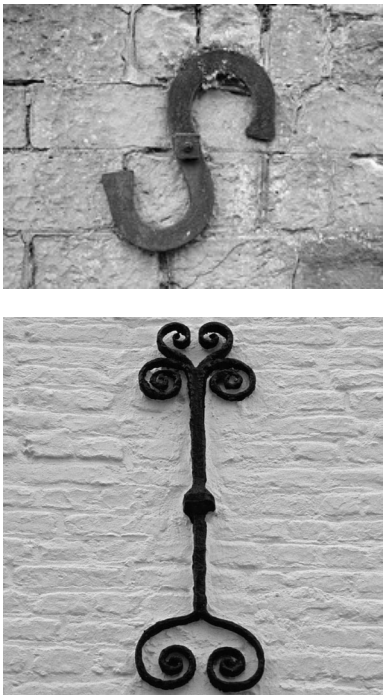
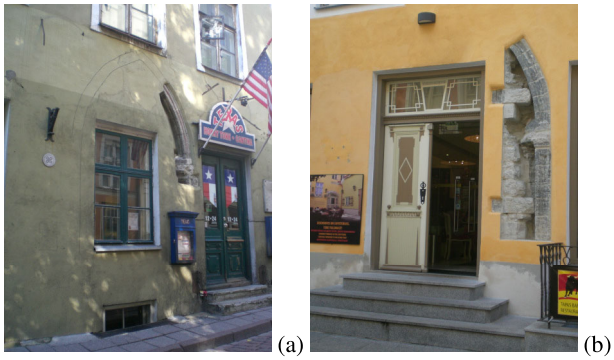


Figure 6: Traditional Gothic tie rod anchors

the laboratory. The intuition, study and experience that have accompanied the cognitive path of the anchor plate element, has reduced the complexity of the analysis of structural behavior.
The multi-disciplinary approach has made every brief observation fundamental, from a historic one to multi-media and the single element has become part of the whole picture. The knowledge phase of the anchor plate is complete and necessary information was collected. On then passed to creating a method of analysis attentive to structural effects derived from particular design forms, rather than fulfilling functionality. In The Architectural Record, May 1937, Gropius alludes to the true form of architecture, claiming that the "features equally beautiful" slogan is half true. There are elements such as the North European anchor plates that are charming as they are incorporated into a valuable, balanced, historical context. Functionality is linked to beauty in context and proportion. This is the strength of the object of this investigation. It has to be asked the reason for which an element created to fulfil a purely



(a) (b)

Figure 7: Tallinn: retrofitted building in old town (a), traces of original structure: façade detail (b)

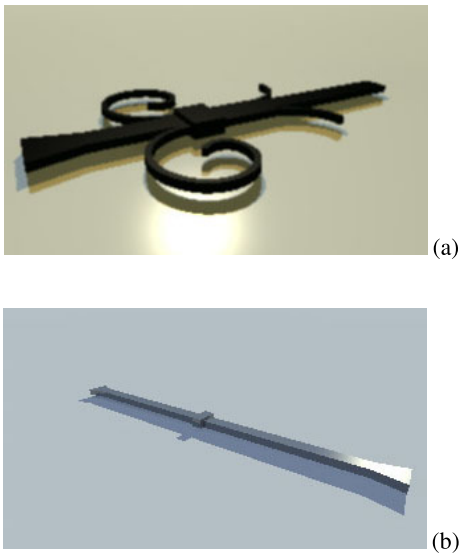
(a) (b)

Figure 8: Tallinn: retrofitted building in old town (a), tie rod anchor (b)

structural function, over time, has managed to acquire a significant role to become a point of attraction of local marketing.

4. STUDY ON GOTHIC AND MODERN STYLE TIE ROD ANCHORS

The structural behavior of the shaped tie rod anchors, and specifically how the two curled elements contribute (with the main stake) to the resistance was performed by a nonlinear static analysis on the masonry tie rod anchor complex. The analysis was performed using a finite element modelling, and both masonry and steel components were modelled using six and eight nodes solid elements. Figures 10 and 11 show the mesh used for discretizing the tie rod anchor elements and the portion of the rear masonry wall in the presence or absence of the two curls respectively.
The orthotropic material properties proposed by Pande et al. were used to model the masonry structure in the sense of an equivalent homogenized material, based on a strain energy



(a) (b)

Figure 9: Virtual model reconstruction of northern European wrought iron tie rod anchor (a), virtual model reconstruction European bar shaped tie rod end (b)

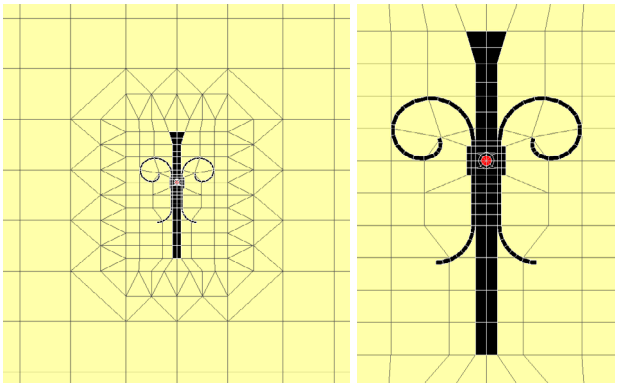


Figure 10: Mesh of tie rod anchor with the two curled elements

concept. The basic assumptions made to derive the equivalent material properties through the strain energy considerations are. (i) bricks and mortar are perfectly bonded, (ii) head and bed mortar joints are assumed to be continuous (therefore, the assumption of continuous head joints instead of staggered joints, as they appear in practice, is assumed to not have any significant effect on the stress states of the constituent materials). Consequently, the orthotropic material properties are function of the brick dimension (length, height and width), thickness of mortar joints, Young's modulus and Poisson's ratio of brick and mortar. Typical values of ashlar masonry with medium-low resistance were used in performing the nonlinear analysis. Namely, brick/block length between 200 and 300 mm, brick/block height between 80 and 120 mm, thickness of mortar bed of 10 mm and thickness of mortar head equal to 5 mm were assumed. The masonry units were supposed to have compression strength f_{bc} equal to 3 MPa, tensile strength f_{bt} = 0.1 MPa, Young's modulus E_b = 2000 MPa, Poisson's modulus equal to 0.15. The mortar was assumed to have compression strength f_{mc} of 1.5 MPa, tensile strength f_{mt} = 0.05 MPa, Young's modulus E_m = 1500 MPa, Poisson's modulus equal to 0.10. A volumetric mass equal to 17 kN/m^3 was finally assumed.

The failure of masonry is then based on a micromechanical behavior. At every loading step, once the equivalent stresses/strains in the masonry structure are calculated, stresses/strains of the constituent materials are derived based on their structural relationship. The maximum principal stress is calculated in each constituent level (brick, bed and head joint) and is compared to the maximum tensile strength. If the maximum principal stress exceeds the tensile strength at the current step, the stiffness contribution of the constituent to the whole element is forced to be negligible. In this way, the local failure mode can be evaluated. Once cracking occurs in any constituent material, the effect is smeared onto the neighbouring equivalent orthotropic material through another homogenization.

The well-known and widely used yield criterion by Von Mises based on distortional strain energy was used for the steel elements. A yield stress of 360 MPa was assumed for both the tie-rod and the tie rod anchor.

The contribution of the two curled elements to the resistance was evaluated by comparing the response in terms of bearing capacity and stress state on the masonry, considering them present or not. The nonlinear FEM analysis showed that the presence of the curled elements does not contribute much in stiffening the tie rod anchor and limiting the maximum stresses on masonry, but significantly influences the masonry area involved by local pressures. Figures 12 and 13 show the deformed shape of both the considered tie rod anchors at a loading level corresponding almost to the maximum one borne up by the masonry. The figures show that in both cases the tie

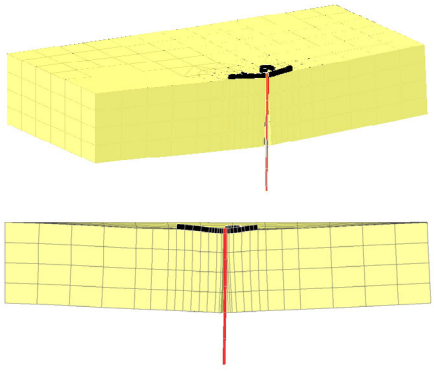


Figure 12: Deformed shape of the tie rod anchor with the two curled elements

rod anchor presents a significant bending, with a variation in displacement between the ends and the tie-rod connection point (where the displacement is maximum and equal to 0.41 mm) of approximately two-tenths of millimetres.

Therefore, high stresses are registered on the masonry at the

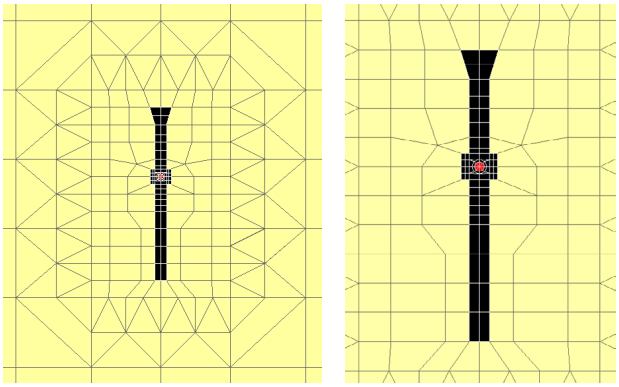


Figure 11: Mesh of tie rod anchor without curled elements

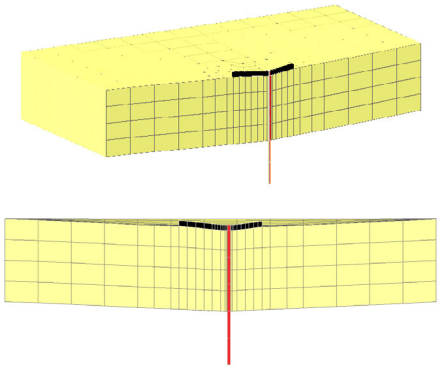


Figure 13: Deformed shape of the tie rod anchor without curled elements

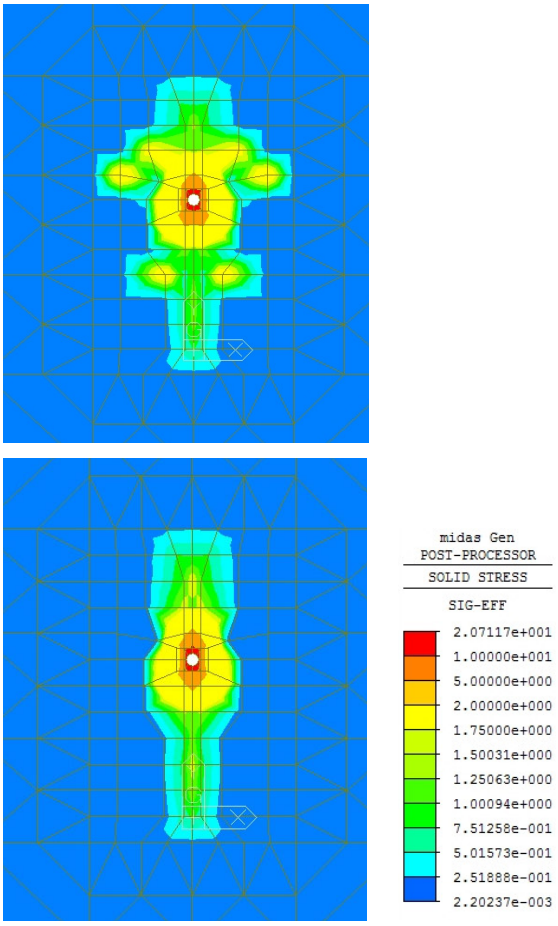


Figure 14: Effective stresses on masonry lying behind the tie rod anchor with and without the two curled elements

(a)

(b)

Figure 15: Tallinn: retrofitted building in old town (a), bar shaped tie rod end (b)

connection of the tie-rod, as shown in Figure 14 where the effective stresses on the masonry wall are plotted at the same loading level of Figures 12 and 13. Then, as it is expected, the stresses around the masonry hole imply local failure of masonry, only partially allowable. Figure 14 instead shows average stresses on the masonry portion involved by the tie rod anchor that are bearable by masonry itself, and, above all, clearly confirms the larger capability of the shaped tie rod anchor with curled elements in distributing the pressure on masonry.

5. CONCLUSIONS

Johann Wolfgang Goethe in the "Writings on art and literature," says that art must be able to represent nature by imitating it without knowing it and presenting it in its own way. The style of an artist is formed when the universal element of nature is represented and it causes what is termed as emotion dictated by the rules of art. These are the foundations of the ancient Northern European craftsmanship that add emotion to make use of the stylized nature of the object (leaf, flower, branch), the elevated aesthetic and historical value and the skilful technical intuition of structural efficiency. The Rules of Art are recipes to be preserved as a basis for progress in the right direction.
They successfully combine knowledge of the structural Cartesian “tie rod anchor” and the symbolism attached to it in the Gothic period and lead to an integration of reasons for its simple response to stress with reasons for its Leibniz shape (intensive, internal and romantic). In the Baltic Gothic period, geometric and mathematical thought unites with typological and morphological thoughts. The drily defined rod becomes recognised as an element, a symbol of belonging to a noble decoration. The streets and houses in Stockholm and Tallinn express their story through the structural elements that become intensive. The emphasis of the facades and structural

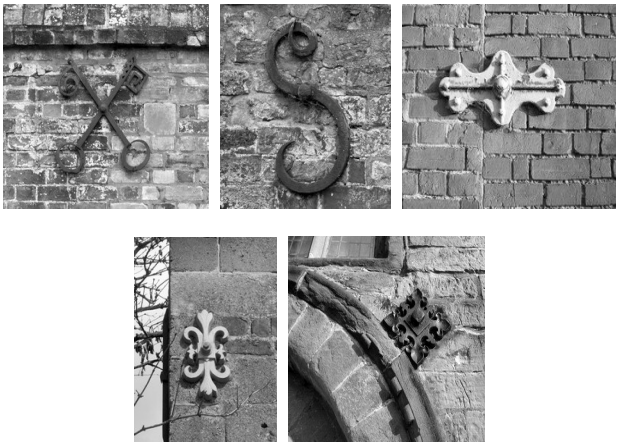


Figure 16: Decorated wrought iron tie rod anchor

strengthening systems combine to create new contexts in ancient systems. Modern urban design choices lead to careful study of philological structural elements, bearers of history. Critical reading of a typical prospectus of northern European cities reacts with theories and urban programs that cancel the past and in a modern way protect the signs of a cultural antecedent. Tallinn, Kultuur kutsub 2001 (Culture European Capital in 2011) fully describes the intelligent urban renewal project, resulting from careful and thorough study of morpho-typological importance of structural elements. Being able to use new technologies to ensure the protection and safety of the cultural heritage is essential to maintain the identity of a place. The efficiency that quality traditional crafts material can provide in terms of long term durability, minimizes maintenance time and allows one to monitor structure degradation. The proven efficiency of the Gothic shaped tie rod anchor, raises the role of this structural element that becomes a symbol of a community and does not just fulfil its technical task.

References

Argan G.C., (1951). *Walter Gropius e la Bauhaus*, Einaudi Ed., Torino, Italy. (in Italian)

Ashby, M.F., (192). *Materials selection in mechanical design*, Pergamon Press, Oxford.

Auch Schwelk, H. & Rosenkranz, F., (2005). *Atlante dei materiali*, UTET Ed., Torino, pp. 66-75. (in Italian).

Contal, M.H. & Revedin, J., (2009). *Progettare la sostenibilità*, I maestri di una nuova architettura, Ambiente Ed., Milano, pp. 9-18. (in Italian).

De Fusco, R., (2009). *Storia del design*, Laterza Ed., Roma, Italy. (in Italian).

De Fusco, R., (2012). *Filosofia del Design*, Einaudi Ed., Torino (in Italian).

Dowling, D., Samali, B. & Li, J., (2005). An improved means of reinforcing adobe walls-external vertical reinforcement, SismoAdobe, Lima, Peru.

Gambardella C., (2004). Disegno come governo della modificazione dell'ambiente naturale e costruito, in *Atti del XXV Conv. Int. Disc.Rappresentazione e I Congresso UID*, Lerici, Italy. (in Italian).

Goethe, J.W., (1992). *Scritti sull'arte e sulla letteratura*, S. Zecchi (a cura di), M. Ophalders, P. Necchi (traduzione di), Bollati Boringhieri Ed., Classici.

Jones, D.L., (2007). *Atlante di bioarchitetura*, UTET Ed.,Torino, pp. 124-128. (in Italian).

Muller, D.G., (2006). *Case ecologiche, i principi, le tendenze, gli esempi*, Ambiente Milano Ed., pp. 8-112. (in Italian).

Muller, D.G., (2007). *Case in legno, la storia, le tecniche, gli esempi*, Ambiente Milano Ed., pp. 8-15. (in Italian).

Peters, T.F., (1987) *Transitions in engineering: Guillaume Henri Dufour and the early 19th century cable suspension bridges*. Birkhauser Verlog Basel.

Sattar, M.A.,(1995). *Traditional Housing in Asia: "Present status and future prospects"*, INBAR Technical Report No. 8, R. Rao and Sastry Eds.

www.architettura21.eu, (retrieved May 2010).
www.architetturagiovanile.com, (retrieved May 2010).
www.topboxdesign.com, (retrieved May 2010).
www.trendir.com, (retrieved May 2010).