Damage evaluation of ex Innocenti-Maserati industrial plant structures.

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ABSTRACT: The paper focuses on the evaluation of the actual mechanical and physical properties of the structural elements of one of the dismissed buildings in the area of ex Innocenti-Maserati industrial plant, located in Milano, more precisely in the Lambrate-Rubattino district.

1 INTRODUCTION

The building under investigation, pictorially illustrated in Fig. 1, was devoted, in the past, to the construction of the famous “Lambretta” motorcycle and, more recently, to the Innocenti-Maserati motorcars. The area, owned by AEDES s.p.a., is under the approval process of new urban project which adopts the idea of preserving the steel skeleton of this huge building and of inserting, inside it, new buildings for different functions.

The investigations of damages, originated by chemical and physics attacks, and the related structural assessment have to support the design of architects, evaluating the actual structural safety indices, by using non destructive and semi destructive methods.

In 1933, he started the production and the distribution of steel pipes and connections of the well known Innocenti Scaffoldings System (originated by a system of the British Scaffolding Company). The Milano-Lambrate industrial area started its development in this year.

The “Fratelli Innocenti Società Anonima per Applicazioni Tubolari in Acciaio”, became one of the most important Italian manufacturing reality. The production ranges from civil to industrial buildings, from cars to weapons components.

In 1944, part of Milano-Lambrate industrial buildings were destroyed by bombing (see Figure 2). Nevertheless, at the end of the 2° worldwar, in 1948, the buildings were recovered and the production of most popular Lambretta started with a production of 250 units per day. Later on, the Mini Minor, in concession to the Britannic BMC, and a Spider, designed by Bertone, were constructed.
In the seventies the importance of Innocenti production declined and the factory in Milano-Lambrate has been sold to the British Leyland, later to Maserati. In the nineties the factory in Milano-Lambrate was dismissed, and the area become one of the largest urban void in Milan.

3 DESCRIPTION OF THE STRUCTURE

The oldest of four industrial buildings covers an area of 75x310m: it is divided in three aisles, 25m wide, and with elevation at the top of about 19.50m. The structure in elevation consists of:

- principal portals, disposed on three aisles, with distance among them of about 10m (Portals "A") (see Figure 6), and
- secondary portals, equally outdistanced among them every 10m, which have not central columns (Portals "B"), (see Figure 6).

The columns result, therefore, to alternate every 10m, while the coverage portals every 5m.

The steel columns are composed by UPN profiles, jointed by welding to steel plates. There are three different kind of columns:
- Lateral single columns;
- Lateral double columns;
- Central triple columns;

The central columns, (see Figure 3), are made of two external columns, that carry the bridge crane beams (see Figure 3). These columns raise up to about 7.5m. The central column continues upward, by connecting itself with the polygonal five sides arch truss, that terminates, on the top, with the lantern. The bridge crane beam is shaped as a double "T" section, which measures 100x51cm. It is made of four UPN sections connected to plates by means of nails (see Figure 4). The polygonal arch truss is composed by three parts, jointed by bolts (see Figure 5). The foundations of the columns are made of isolated reinforced concrete plinths, with underlying reinforced concrete piles of about 2-3m of depth.

4 DEGRADATION EVALUATION OF THE INDUSTRIAL BUILDING

The investigations to evaluate the degradation of the structural elements are subdivided into two phases:

- phase 1: limited number of tests for the evaluation of the physical, chemical and mechanical properties of the most damaged and most undamaged structural elements in order to identify a possible range of the mechanical properties;
- phase 2: extensive non destructive investigations for the verification of the integrity of all the structural elements with substitution and integration of the obsolete ones.
4.1 *Evaluation of the distribution and degree of corrosion’s attack in steel structural elements.*

The plan of investigations has been preceded by an historical investigation, followed by a visual inspection; that has allowed to hypothesize the necessary steps to be taken in the following operations.

The characterization of level of corrosion is done by Department of Chemical and Material Department and Chemical Engineering of Politecnico of Milan.

The evaluation of the diffusion of corrosion has been done according to the normative ISO 4628-3 (Bertolini, 2008.).

The degradation has been established according to the following ranking:
- R1: when the rust is distributed on 0.05% of the surface;
- R2: when the rust is distributed on 0.5% of the surface;
- R3: when the rust is distributed on 1% of the surface;
- R4: when the rust is distributed on 8% of the surface;
- R5: when the rust is distributed on 40-50% of the surface;

The extension of the attack has been classified in base to the percentage of area interested by corrosion of the structural element:
- A: < 5% of the total surface;
- B: 5-10% of the total surface;
- C: 10-40% of the total surface;
- D: > 40% of the total surface;

The degree of propagation of the corrosion doesn't result constant in all elements.

For example in the columns it results that:
- the degradation type R5, present for the 20.4% of the columns, is located mainly in the North zone and only in some single cases in the rest of the building;
- the degradation type R4, present for the 33.7% of the columns, is located mainly in the East zone; the degrade type R3 is present for 45% of the columns.

The degradation for the elements that constitute the beam bridge crane, is verified in function of the exposition:
for the mandrel and the superior wing,
- the R5 degradation type, present for the 1.1% of the totality of the beams;
- the R4 degradation type, present for the 15.1% of the totality of the beams, is verified in the West South zone of the shed;
The laboratory’s tests have been performed on steel plates and on bolted, nailed and welded joints, after a suitable choice of specimen, with different degree of corrosion, which have been cut from the structure.

The chemical and metallographic analyses have been done at DCMIC laboratories (Bertolini, 2008) while the mechanical tests at LPM of DIS, Politecnico of Milan (…….., 2008). The chemical and metallographic analyses (see Figure 8, 9, 10), underline that the steel plates, and the UPN sections, have the same type of microstructure containing small quantity of carbon 0.02-0.04%, and are primarily constituted by ferrite-cementite’s particles with inclusions.

As regards the bolts, which connect the beam with the column, they have a ferrite-perlite microstructure; the welding fillets are in good state of maintenance, with modest corrosive attacks.

Considering the corrosion attacks, it has been verified that the degree of damage is not the same for all structural components.

For example, the metallographic analyses (by electronic microscope) have shown that the reduction of thicknesses in the columns is:

- for the degree R3, in which the products of the corrosion occupy a fraction reduced of the surface and partial separations of the protective painting and reduction of the thicknesses for the plates is inferior to 100 µs m and for the welding to 100-200 µm;

- for the degree R4, where the products of the corrosion occupy a great fraction of the sur-
face, with great separations of the coverings, Figure 8. Corrosive attack between the plates. The reduction of the thicknesses of the plates is of the order of 160 µm (see Figure 9);

- for the degree R5, the products of the corrosion show a surface covered for a fraction raised by products of the corrosion with reductions of thickness that go from 100 µm to 3 mm and in some points to the suit consumption of the thickness of the plates.

The mechanical tests, developed in DIS laboratories, (Department of Structural Engineer laboratories), allowed the characterization of the steels, of the plates and bolts.

The tests have been reported with the degree of corrosion to verify the possible fallen of mechanical propriety of the steel due to the corrosive phenomena.

The tensile and the resiliency test, practiced to steel sample have been done in according to UNI 10025-1; the tests seems to confirm the hypotheses of degrade established by the chemical analyses, according to which the degrade has interested only the reduction of the thicknesses of the plates but not the morphology and the mechanical performances of the steels.

The bolts have been tested in according to UNI EN ISO 898, tensile test on grapevine and imprisoned grapevine;

The connection by nails and welding are been made simulating the actions to which are stressed.

The nail’s connection in the particular case, result stressed by a strength orthogonally to the axle of the nail.

The shear action on the same can provoke:
- the cut breakup of the nail;
- the breakup of the plate, for tensile action.

The welding unions, have been tested with tensile test in correspondence of the section of the cord.

4.3 Geometric relief and definition of the state of the structures of foundation

The problem of the discontinuous structures of foundation, plinths and piles, have been:
- definition of the geometry, particularly of the piles;
- material characterization and degrade;

The measures have been practiced in correspondence to three typologies of plinth, tied up to the different characteristics of the structures in elevation. All the piles are surmounted by the plinth of foundation: it has been therefore employed the "echo metric method" sending and receiving the signals of the propagation of the mechanics impulses along the stem of the pile (see Figure 12).

The measures have been performed in conformity to the Norms ASTM D 5882. 00 and NF P 94-160 -2.

The length (L) of the element to be investigated is gotten with the simple relationship:

\[ L = \frac{V_m \cdot t}{2} \]

in which:

\( V_m = \) is the medium speed of propagation of the mechanical impulse in concrete.

\( t = \) time intervened between the issue and the receipt of the signal, reflected by the end of the pile.
The evaluations of the length of the element are done attributing two values limit to the speed of propagation of the elastic wave commonly assumed for concretes of this type: 3700 - 3900 m/sec. Being the piles overhung by the foundations of the structures in elevation, the immission and receipt of the signals has been served as the stems of the piles by the opening of a special niche created in the concrete on the top of pile.

Figure 12. Graphs of the echo metric signals.

The graphs that represent the echo metric signals are of good quality and legibility; this allows to formulate the following conclusive observations:
- The lengths of the piles deduced by the echo metric’s measures can be considered real;
- The light anomalies found along the stem of the piles can be considered negligible in how much of light entity.

Besides, these intermediary reflections could be due to the presence of possible stratigraphical variations that could have modified the geometry of the pile on the spot or, however varied the dynamic behaviour of the piles themselves.

The evaluation of the state of the structures of foundation the structures of foundation individualized (Bertolini 2008.), have been examined by the personnel of the DCMIC Politecnico di Milano, that have performed some non destructive investigations that have allowed to define:
- the position of the reinforced bars of the plinth with the use of pacometro;
- the resistivity of the concretes;
- the level of carbonation of the concretes.

The concrete of the foundation is in good state of conservation and the reinforced bars have not problem of corrosion.

5 CONCLUSIONS

The preliminary analysis give us the information necessary to create the structural modeling analysis, performed to residual thickness of the plates and junction elements; in the same time we obtained all the information to create the Guide Lines for correct rehabilitation of the structure.

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