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“NANOTECHNOLOGIES FOR CONCRETE AND COMPOSED STRUCTURES FOR SEISMIC SAFETY”

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ABSTRACT

Performance requirements of civil structures are becoming more and more severe in recent years. Users pay an increasing attention to safety and functionality of systems and components over time, because of the impact of failure and/or down time from the social and economic point of view. The market globalization and the transfer of technologies among different branches of engineering and material science are also influencing the concept of safety of civil structures – buildings, bridges and other critical infrastructures. A different paradigm in the field of building and infrastructure technology has been envisaged and investigated. In particular, issues like degradation control and assessment of materials and components in order to enhance durability of structures and overall performances of the constructions are focused; moreover, emergency management, structural safety and performance monitoring of structures exposed to natural risks such as earthquakes are targets of recent researches. The industry of the constructions must face problems related to the maintenance of structural elements in concrete or to mixed structure. In virtue of such problem list in the last years it has also spread the use of concretes to high technology with particular characteristics of seismic resistance. The use of this concrete allows to overcome the connected difficulties with the geometric complexity of the structures and the problems originated from sections to tall percentage of armor. The addition, then, of fibers of reinforcement in partial or total substitution of the traditional metallic armor it allows to get best performances both static that dynamics of existing structures.

1. ADVANCED MATERIALS

The advanced materials employed in building sector often derive by processes of technological transfer from other industrial sectors characterized by strong pushes to innovation (typically aeronautical, car industry and biomedical). In these sectors the search in the field of materials with elevated performances more and more constitutes an essential condition for the development of products and efficient systems. Taking into account that, generally, in building, from the point of view of both industrial production and architecture design, the innovations are absorbed in times longer than in other sectors, in order to ensure that these materials are received in ordinary construction processes, adaptations and verifications of the use performances are necessary, practices which, on the other hand, together with the technical difficulty of using advanced materials and the lack of specific regulations, they tend to delay their spread.

The recent development of knowledge in the chemical field has radically changed the relationship between man and matter. In fact, through the manipulation of molecular atomic structures it is possible to set up numerous new complexities managed by materials, in which impurities and anisotropies are purposely designed to obtain very punctual performances.

The material identity of the object is replaced by performance, changing a reference code that for centuries has helped man to know the surrounding world. The materials of recent generation cannot be classified according to consolidated parameters since they present a continuum of possibilities with unpredictable behaviors.

2. THE ROLE OF ADVANCED MATERIALS IN SAFETY DESIGN

The family of new materials appears extremely heterogeneous and difficult to classify according to traditional criteria. The main element that distinguishes it, does not derive from the fundamental properties of the material itself, previously described by its material content, but rather from the possibility of attributing extraneous and original characters that increase the information content by intervening on different dimensional scales.

The levels at which it is possible to intervene on a single product today are many and vary their dimensional scale based on the properties they want to confer.

For example, by manipulating the atomic structure of a material it is possible to modify the general characteristics that distinguish the three large families of ceramic, metal and polymeric products. Furthermore, by acting on the type of spatial distribution of atoms and on the intensity of their bonds it is possible to change the state of aggregation from solid to liquid or gaseous, in order to create new metal alloys and ceramic materials with high specific performances.

The physical-mechanics properties that determines the type of current positions in a polymer, depend from the type of microstructure, while from the macrostructure it is possible to manage the stickiness properties of a composite by modifying the combination of quantity of fibers and matrices present.

These materials are generally characterized by properties that, compared to normal building materials, are optimized for the specific use defined. They can provide variable, selectable and controllable performances, in order to modify their physical-chemical properties in relation to the stimulus received, introducing new services that cannot be reached or considered previously.

Since the principal difference between new and traditional materials resides in the abilities performance and not only in a detail or unpublished conformation physical-chemistry, also traditional materials “innovated” in their performances an be considered “advanced” to all effects. Equally particular productive and of synthesis trials can identify some classes of advanced materials (it is thought the nanotech materials to resultant by the joining of two or more materials).

With the definition of advanced innovative materials are generally pointed out all those custom designed ceramic, metallic or polymeric materials for satisfying one or more demands.

These types of materials differ from traditional ones not so much because they are made in more recent times, but because they introduce a high degree of function or design by intervening on their physical and chemical structure to vary their information content and increase performance levels.

The speed with which the world of science offers us new materials and technologies with enormous potential, together with the properties of thermoplastic ones, an integral part of our industrial heritage, already offers a concrete possibility to develop innovative materials with unprecedented performance.

- Nano fillers:
  Nanotechnology generally consists of studying the change in the properties of the particles as the dimensions vary below 100 nm. The reason why nanocomposite materials are potentially very interesting comes from the high surface interaction that is created between polymer and nanoparticles which gives rise to considerable variations in the physical-mechanical properties of the base polymer.

- Special fillers:
  The introduction of fillers such as aramid fibers, carbon or steel, as well as ceramic inserts inside the polymers, improves those specific characteristics that make them particularly suitable for uses in which the operating conditions are discriminating compared to more traditional metals.

- Advanced polymers:
  The high degree of reliability and quality achieved by the multinationals in the production of basic polymers, combined with their ability to focus on a few increasingly refined products, constitutes the development base for innovative niche materials.

3. TYPOLOGIES AND CHARACTERISTICS

Among the advanced materials currently used in the construction it is possible to select two main families:

- materials with fixed performances, in which the final properties are selected and predetermined through particular chemical-physical conformations and synthesis processes, and intelligent materials capable of varying the characteristics when stressed by the external stimulus.

Among the materials with fixed performances it is possible to distinguish:

- advanced structural materials what fiberenforced composite, concretes with high performances, structural glasses, metallic and polymeric foams, employed in different typologies of applications in which the function is predominantly expressible in terms of mechanical performance;
- Thermostructural materials, such as flame retardant and flame retardant fibers, thermosetting resins, advanced ceramics, transparent ceramics, high-performance ceramics, ceramic foams and light ceramics, with high thermo-mechanical performance;
- Materials with surface and interface performance, such as wear-free, anti-corrosion, thermal and photocatalytic coatings and coatings; self-cleaning, selective and low-emission glasses, which when used in buildings wrap must provide a high level of protection against various environmental factors from chemical-physical conformations.

On the other hand, it is possible to divide intelligent material into two main categories:

- Materials that change properties and memory of the materials of form. They can change their chemical, mechanical, optical, electrical, magnetic or thermal properties, based on changing environmental conditions without requiring an external control system;
- Energy exchange materials; organic materials for photovoltaic conversion, capable of transforming one form of energy into another, according to the first thermodynamic principle. They are used in buildings as devices for energy production and control systems.

It is worth noting that this classification includes types of materials whose application in the building is well established (the fiber reinforced composite is, for example, used for the consolidation of existing structures or for the construction of light and resistant structural components).

In particular, the single-walled nanotube has a high tensile strength with a breakup tension comparable to the theoretical value corresponding to the carbon-carbon bond in a benzene ring. This makes it the most resistant organic material in the world: it has, in fact, a tensile strength 100 times greater than a steel bar, but with a weight six times lower. Furthermore, it is important to remember that nanotubes are not only resistant to tensile failure, but they are very flexible and can be folded without breaking or damage. The extreme resistance combined with flexibility makes them ideal for buckyballs.

4. NANOTECHNOLOGY FOR SEISMIC PROTECTION OF INFRASTRUCTURES

The maximum seismic action exerted on a built system is well described by the flexible spectrum, which indicates the maximum seismic acceleration of the system based on its vibration period.

As it is known in most structures, the maximum amplification is characterized by periods of 1 s or more (> 2 s) and in this case the most deformable structures are characterized by a reduced vulnerability to earthquakes. At the same time the problem triggered by the maximum duration of the vibration period cannot be neglected because it involves the danger of the collapse of non-structural parts of the building [Clemente, 2017]. This is the reason that drives the definitive and widespread use of seismic insulators between foundations and elevated structures, this is increasingly valid also for civil engineering works and, in particular, for bridges.

The study of the characteristic of the deformation and of the tension of the structure is always carried out through a series of simplifications and hypotheses which make it possible to trace from the real case back to the "theoretical model" of calculation that adapts it to the limit of our knowledge and intuitions, this is particularly true also for bridges.

In the most doubtful cases, where the definition of a suitable "theoretical model" is uncertain or the calculation procedures are arduous or non-existent, at the planner level is the experimenter and in "theoretical model" is the "experimental model" which confirms or reveals why not we can specify or know with the theory.

A real bridge, for example, is always a spatial system and "the theoretical models" should always belong to such category. Actually, the necessity of easy and expeditious calculation determines a first simplification, i.e., to study the bridge as "one-dimensional plain system". Remembering the limits of extension of de Saint Venant problem, this is allowed when the following hypotheses subsist:

a) the geometric axis of the beam is on a plan;
b) the generic cross-section has such geometric characteristics, so that one of its inertial central axes is contained on a plan;
c) stresses, strengths and distorsions work in such plan.

Since, with the exception of oblique and curved bridges, the hypotheses a) and b) are satisfied, the cross-sections being always symmetrical, it is to consider the stress analysis only.

While the deformations are always symmetrical with respect to the plane of the system and it is therefore legitimate to consider them as agents on this plane, the same cannot be said for the strengths, which can be classified into:

a) forces resulting in the system plan;
b) normal forces resulting from the system plan;
c) bending resulting from transverse forces with respect to the axis line.

In summary, the analysis of a bridge is carried out in two separate phases [Reithel, 1964]:

a) the system is considered simple and the corresponding stress and tension system is described;
b) the factors that determine a difference between the previous results from the actual ones (deformability of the cross section, actual application of the strength points) must be taken into consideration. They determine the corresponding deformation system and the effort that overlaps the first one.

It seems evident, therefore, that the use of nanotechnologies with characteristics of resistance superior to ordinary concretes including a strong tensile strength, ensures the greater reliability of the model adopted in terms of a more efficient seismic protection.

From this point of view, the performances currently required of such delicate and particular structures seem to be achievable entirely with the use of nanostructured concrete that can also be used to consolidate existing structures, as would appear to be apparent after the recent events in Genoa: the collapse of one of the bridge spans designed by Riccardo Morandi and inaugurated in 1967.

5. NANOTECHNOLOGIES FOR DYNAMIC INTERACTION FOUNDATION – STRUCTURE

One of the possible technologies that can be applied in a seismic zone is seismic isolation. The concept of scientific isolation was developed about 150 years ago, in 1868, by Scottish engineer David Stevenson when the study of seismic engineering was at the initial development. However, references to this anti-seismic protetion systems also exist in the construction of temples or public buildings since the time of ancient Greece. The awareness of the application of this anti-seismic technology is typical of the second half of the twentieth century when scientific thought confirmed the interest in this solution aimed at separating two rigid parts of a building to produce an attenuation of the effects on the entire structure [Carpani, 2017].

In synthesis, the basic hypotheses of the soil-structure dynamic interaction can be summarized as it follows [Lai, 2011]:

a it is not significant in case of flexible structures on rigid grounds
b it can be important for rigid structures on deformable ground
c the fundamental period of vibration of a soil-structure system is longer than that correspondent to a built structure;
d the real damping of a soil-structure system is higher than the structural one;
e total movements may increase due to interaction effects and may be important for higher structures;
f to ignore the interaction is equivalent to assume the structure founded upon rock.

The isolation technology involves the development of the column isolation technology (jet grouting technology) which, appropriately assembled and designed from the geometric and performance point of view of the mechanical-physics according to the nanotechnological mixtures, is able to:

a) mitigate the seismic actions for existing buildings, preserving the level of safety towards gravitational actions and in operating conditions, without affecting any kind of formal integrity:
b) mitigate the effects of vibrations produced by anthropogenic conditions (vibrating cars, trains, etc.);
c) realizing highly efficient and reliable hydraulic barriers even in the presence of polluting agents.

The researches developed nowday have, infact, underlined that:

- for objectives a) and b): it is possible to weaken the propagation of shear waves (of anthropogenic or seismic origin) by introducing in the mass poles of nanotechnological material with physical-mechanical performances different from those of the soil. In particular, the idea consists in the introduction of a relatively thin layer of material characterized by a dynamic impedance lower than that of the surrounding soil. Numerical analyzes and laboratory tests have shown that when the relationship between the impedance of natural soil and the material that makes the barrier to vibrations reaches values of 20-30, geometrically mounted barriers allow a reduction in the propagation of vibrations[1]. The research activities in the field of technology applied to geotechnical engineering and structural design have made it possible to find the optimal geometrical configurations, which differ in the operation of some considered (seismic risk mitigation or from anthropogenic vibrations). This allowed us to identify some nanotechnological materials suitable for the intended purpose. Although research has also been carried out on original material, the existence has been verified eco-friendly products (in such a way that they can be introduced into the ground without polluting and causing environmental damage) it has been verified that it can be used with great simplicity and economic convenience. For this application, we will also consider the possibility of adding the injections in order to make the porous columns, in order to reduce the density of the material (beneficial dynamic effect) and increase the hydraulic permeability of the barrier, to make this application does not disturb the system underground water supply.
- for objective c): it is verified that the materials studied to satisfy the objectives a) and b) could also be adapted to the achievement of the same objective. As previously written, in fact, the reduction of vibrations must be obtained with a material that can be light but has, above all, a low speed of shear waves and is therefore very deformable. The materials that have been identified with these characteristics may have implemented a slightly modified composition to give place to the columns with practically zero permeability, very deformable.

It is interesting to note that all possible applications are extensive and that jet grouting technology must be considered as a mixture from a basic chemical component, water and earth, possibly with variable operating percentages for specific applications to be solved. In other words, the proposed product will be adaptable to different needs in a simple way through a percentage variation of the basic components and therefore with nanotechnological performances.

This technology is absolutely innovative both in the field of defense from vibration and in that of environmental defense. For the first application, in particular, the seismic isolation of existing buildings is an unresolved problem and, in fact, it usually intervenes reducing the vulnerability through interventions that are invasive and that are particularly expensive. With particular reference to the structures of merit, which characterize the Italian architectural heritage, traditional technologies for the reduction of seismic vulnerability must be such as not to compromise the historical and material integrity of the structure to be protected and must guarantee the reversibility of the applications. This can make the intervention on the considered structures particularly complex.

With reference to risk mitigation, the technology developed can represent a reliable solution for the seismic adjustment to merit or existing strategic buildings in the event of natural events. In this sense, the advantages depend on the durability of the solution's effectiveness and on the possible controls.

It is estimated that the consequent benefits deriving from the application of the insulation of the column, both in terms of life cycle cost and in terms of the characteristics of the overall performance of the structures, can have a 30% reduction in labor costs. With reference to the structures of strategic interest it is possible to obtain a significant reduction in costs if we consider the post-earthquake use.

[1] The general characteristics of the dynamic soil-structure interaction through the method of impedance dynamics functions are:
- general methodology to define the dynamic response of a foundation;
- assimilation of the earth-foundation system to the assembled mass system;
- hypothesis of the system of harmonic vibrations;
- easily generalizable to non-harmonic vibrations with the Fourier theorem;
- development of calculation codes for more common bases.

6. CONCLUSION

It appears evident as the introduction of nanotecnologies allows to raise notably the resistance of concrete introducing, of fact, the ductility concrete concept produced by the strong traction resistance and, accordingly, by elevated control of cracking. Such consideration appears well work in circle of capacity design together possibility of realization of plastic hinges. It needs however to underline as it still appears relatively missed the behavior in seismic zone of such structures to withdrawal and fluage that constitute a grey zone still within the viscous deformations and on their relapse on maintenance of performances of seismic resistance.

The viscous deformations are related to the composition, the loads and the maturation of the concrete. It can be stated how the nanotech concrete, made with a suitable mix-design and matured in predetermined times, can make this negative influence of the rheological factors less important thanks to the high resistance to loads. This is directly influenced by the workability which is the most complex performance to be considered fresh. It is not possible to characterize the workability with a numerical parameter but the studies already carried out allow us to state whether, to frame the phenomena connected to workability, it is necessary to follow the rules of rheology defining the characteristic parameters such as the coefficient of internal friction and cohesion [De Sivo, Cito, Iovino, Irace, 1987]. The better workability influences the value of the porosity and, therefore, of the compactness. Faury has verified that in a unit volume of porosity of the fresh concrete can be calculated with the expression:

$$I = \frac{K}{\sqrt[5]{D_{max}}} + \frac{K'}{\frac{\rho}{D_{max}} - 0{,}75}$$

where:

ρ = mean radius of the shuttering
D_{max} = maximum diameter of the inert
K = dependent coefficient from the inert nature (Table 1)
K′ = dependent coefficient from the installation (Table 2)

CONCRETE	ROUNDED EDGES INERTS	ROUNDED EDGES INERTS AND BIG INERT WITH SHARP EDGES	SHARP EDGES INERT
Soft texure– normal compacting factor	0,370	0,405	0,450
Firm texture – very accurate compact factor or normal vibrating	0,350 – 0,370	0,375 – 0,405	0,430 – 0,450
Very firm texture – strong vibrating	0,330 – 0,350	0,355 – 0,375	0,400 – 0,430
Wet ground texture – very strong vibrating	0,250 – 0,330	0,330 – 0,355	0,350 – 0,400

TABLE 1. Value of K.

CONCRETE	K′
Normal compacting factor	0,003
Strong vibrating	0,002

TABLE 2. Value of K′.

Therefore, by using nanotechnological concretes, reduced values are obtained, mainly of K value.
Still within the frame of the rules of technology in seismic areas, and expeially in the context of the local structural interventions, the nanotech concrete coating technique can achieve all or some of the following objectives:
- increase in vertical resistance capacity;
- increase in flexural or shear resistance;
- increase in deformation capacity.

The thickness of the local intervention must be such as to allow the positioning of longitudinal and transverse reinforcements. For the evaluation of the strength and deformation of the structural elements the following simplification hypotheses are acceptable [Catalano, 2016]:

- the structural element involves monolithically with full adherence between old and new concrete;
- the fact neglects that the axial load is applied only to the pre-existing element and is considered to act on the entire section;
- the mechanical performance of the concrete is considered to be extended to the entire section if the differences between the two materials are not excessive.

The performance values to be adopted in the verification are calculated by referring to the structural section in the simplification hypotheses reduced according to the following expression:

- cut resistance V = 0,9 V
- flexural strength: M = 0,9 M
- yeld strength: θy = 0.9 θy
- final deformation: θu = θu

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