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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 focussed; 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 employees in building circle often derive by processes of technological transfer from other industrial sectors characterized by strong pushes to innovation (typically aeronautical, car industry and biomedical), in which the search in the field of materials with elevated performances more and more constitutes an essential condition for realization of products and efficient systems. Since generally in building the innovations are absorbed in times longer than in other sectors, both from the point of view of industrial production and architecture design, so that such materials are acquired in common routine constructive processes they are necessary adaptation and verification of performances under conditions of use, that, with difficulties technical operational tied up to the employment of the advanced materials and the absence of normative specifications, they have the tendency to delay its diffusion.
The recent development of knowledges in chemical field has changed radically the relationship between man and matter conferring the possibility to manipulate the molecular atomic structures setting numerous new complexities materials managed, in which the impurities and the anisotropies on purpose come projected to get very punctual performances.
The matter identity of the object is replaced by performance changing a code of reference that for centuries the man had helped to know the surrounding world; the matter of recent generation is unclassifiable according to consolidated parameters since proposes as a continuum of possibility with unpredictable behaviors.

2. THE ROLE OF ADVANCED MATERIALS IN SAFETY DESIGN

The family of new materials appears extremely heterogeneous and hardly classifiable according to the traditional criterions since the principal element that it distinguishes doesn't result to derive by the fundamental ownerships of the same material defined previously by its matter content, how much rather by the possibility to attribute extraneous and original ownership that increases its informative content intervening on different dimensional staircases. The levels to which it today is possible to intervene on a single product are manifold and they vary their dimensional staircase according to the ownerships that it wants to confer. For example, acting on the atomic structure of a material it is possible to intervene on his general ownerships that distinguish the three great families of ceramic, metallic and polymeric products; acting on the type of spatial distribution of atoms and on intensity of their bonds it is possible to modify the state of aggregation from solid to liquid or gaseous, for example, for creation of new metallic and material leagues ceramic to elevated specific performances. From the type of microstructure derive physical-mechanics propriertes what the type of present positions in a polymer and from the macrostructure it is possible to manage the ownerships of tackiness of a composite modifying the combination among quantity of fibers and present matrixes. Such materials are generally characterized by ownership optimized in comparison to the communes building materials in relationship to the specific anticipated employment, they can be able to furnish varying performances, selectable and controllable, to modify the own physical-chemistry properties in relationship to the received stimulus, thin to introduce new performances not attainable neither considered in precedence.

Since the principal difference in comparison to the 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 it are to consider "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 is generically pointed all that custom projected ceramic, metallic or polymeric materials out for satisfying one or more demands. Such materials differentiate from traditional not so much because realized in more recent times, but because introduces a tall degree of function or design intervening on their physical and chemistry structure to vary their informative content and to raise its performances levels.

The rapidity with the world of the science proposes us new materials and technologies with enormous potentialities, together to the ownerships of thermoplastic ones, integral part of our industrial heritage, offers already a concrete possibility to develop innovative materials with never before been contemplated performances.

· Nano fillers:

The nanotechnology generally represents the study of the in partnership change of the ownerships to the variation of dimensions of particles below the 100 nm. The reason for which the material nanocompositis are potentially very interesting drift by the elevated superficial interaction that it comes to create between polymer and nanoparticles giving origin to remarkable variations in the ownerships physical-mechanics of base polymer.

· Special fillers:

Introducing fillers what the aramidiches, carbon or steel, as well as the ceramic ones inside the polymers, improve it notably some specific characteristics making them particularly proper for that types of employment where the operating conditions are discriminatory in comparison to the most traditional metals.

· Advanced polymers:
The elevated degree of reliability and quality reached in the production of the polymers of base by the multinationals, together to their ability to focus on few products more and more improved, it constitute the base of development for the niche innovative materials.

3. TYPOLOGIES AND CHARACTERISTICS

Among the advanced materials currently employees in building it is possible to individualize two principal families: materials with fixed performances, in which the final ownerships are selected and predetermine through particular conformations chemical-physics and processes of synthesis, and smart materials, in degree to vary characteristics in answer to external stimulus. Among 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;
· thermo-structural materials, what flame-retardant fibers and retardant flame, thermosetting resins, advanced ceramics, transparent ceramics, high performance ceramics, foams ceramic and light ceramic, with elevated thermo-mecanical performance;
· materials with superficial and interface performance, what coverings and coatings nanostructured wear-free, anticorrosive, thermal and photocatalytic; self-cleaning glasses, selective and low-emission, that if employed in the buildings wrap they are to furnish an elevated protection by environmental factors of various type by chemical-physics conformations.

It is possible, instead, to divide the material smart in two principal categories:

· property changing materials and memory of form materials, that modify some ownerships (chemical, mechanics, optics, electric, magnetic or thermal) in answer to the change of the environmental conditions without the necessity of a system of external control;
· energy exchanging material; organic material for the photovoltaic conversion, in degree to turn a incoming energy form into another going out in accord with the first thermodynamics principle, employed in buildings as devices for the production of energy and systems of control.

It is to notice well as such a classification includes typologies of materials whose application in building is consolidated (fiberenforced composite is thought to employed for consolidation of existing structures or for realization of light and resistant structural components).
Particularly, the nanotube by single wall possesses a great traction resistance with a breakup tension comparable at theoretical value corresponding at carbon-carbon bond in a benzene ring that it makes the more resistant organic material in the world: it would have a resistance to the traction 100 times greater of a steel bar, but with a weight six times smaller. Moreover, it must remembered that nanotubes are not resistant to breakup by traction only, but they are very flexible and they can be folded without breaking or damage also. The extreme resistance united flexibility it makes them ideal for buckyball.

4. NANOTECHNOLOGY FOR SEISMIC PROTECTION OF INFRASTRUCTURES

The maximum seismic action that strikes a building system is well described by the flexible spectrum, that points out the maximum seismic acceleration of operation system of its vibration period.
As it is known in the greatest part of structures the maximum amplification is characterized by periods of 1s or higher (> 2 s) and in this case the most deformable structures are characterized by a reduced vulnerability to earthquakes. At the same time cannot be neglected problem baited by greatest duration of vibration period because it involves the collapses dangerousness of not structural parts of building [Clemente, 2017]. This is the motive that pushes to definitive and diffused use of seismic insulators between foundations and elevation structure and more and more this is also worth for civil engineering works and, particularly, the bridges.

The study of deformation feature and structure strain is always effected through a simplifications and hypothesis series that it allow to bring back the real case to "theoretical model" of calculation that he adjusts it up to the limit of our knowledges and intuitions, so also for the bridges. In the most doubtful cases, where the definition of suitable "theoretical model" it result uncertain or calculation procedures are arduous or nonexistent, at planner side it the experimenter and at "theoretical model" the "experimental model" that it confirm or it reveal because we are not able to specify or to know with theory.

The real bridge, for exaple, is always a spatial system and in rigor "the theoretical model" select it would owe in every case to reenter in such category but the necessity of easy and expeditious calculation, that have moreover the advantage to mention the main point, it recommend a first simplification: to study the bridge as "one-dimensional plain system ". This is legitimate when, and remember the limits of extension of de Saint Venant problem, the following hypotheses subsist:

a) the geometric axle of beam content in system plan;
b) the generic straight section has such geometric characteristics that one of its inertia central axes is contained in system plan;
c) stresses, strengths and distorsions, work in such plan.

Since, on the other hand, with only exception of oblique and in curve bridges the hypotheses a) and b) are satisfied where always is kept in mind that the straight sections are always symmetrical, they stay to consider the stress analysis only.

While the distorsions are always symmetrical in comparison to system plan and it are therefore permissible to consider agents in its plan, the same cannot tell for strengths. In fact these can be however varying and direct and the necessary pattern involves for them to be in every section so gathered:

a) forces resultant in system plan;
b) forces resultant normal to system plan;
c) bending resultant of transversal forces in comparison to axle line.

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

a) the system is concerned as plain and are determined the correspondents system of deformation and effort;

b) shall be taken into account of factors that do differ the preceding results from those effective (deformability of transversal section, real way of application of the strengths) determining the correspondents system of deformation and effort overlapping to the first.

It appears evident, therefore, in such optics based on hypothesis of calculation sun, as the use of nanotechnologies with characteristics as before clearly described endowed with superior resistance to ordinary concretes, inclusive a strong traction resistance, allows the best reliability of the model adopted for a best seismic protection of such delicate and particular structures. In fact, the performance currently in demand appear attainable entirely with the use of nanostructured concrete that can be employed also for consolidation of the existing structures to the light of the recent events in Genova with the collapse of one of spans of the bridge designed by Riccardo Morandi and inaugurated in 1967. Particularly, it appears evident as the materials adopted for such last bridge has not overcome, over the resistance, the necessary limits of durability and not noticed by one deepened necessary country of monitoring and verification for maintenance.

5. NANOTECHNOLOGIES FOR DYNAMIC INTERACTION FOUNDATION – STRUCTURE

One of the possible technologies in the seismic zone is seismic isolation. The concept of the isolation scientifically has been launched around 150 years ago, in 1868, by the Scottish engineer David Stevenson when the study of the seismic engineering was in initial development even if references also exist in such sense in the construction of temples or public buildings since the epoch of ancient Greece. The awareness of application of such antiseismic technology is proper of the second halves the twentieth century when the scientific thought confirmed the interest for such solution to separate two rigid parts of a building for attenuation of effects on the whole structure [Carpani, 2017]. In synthesis, the dynamic interaction ground-structure has hypothesis to the base that it can be reassumed 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 system ground-structure is longer than that correspondent to an inserted structure;
d) the real damping of a system ground-structure is higher of than structural alone;
e) the total moves can increase by interaction effects and it can be important for approximated tall structures;
f) to ignore the interaction is equivalent to assume the structure founded upon rock.

With isolation technology it is envisaged developing the technology of column isolation (jet grouting technology) that, opportunely assembled and designed by geometric and performance point of view of physical-mechanics according nanotech mixtures, it is able of:

a) to mitigate the seismic actions for existing buildings, preserving the safety level of it towards gravitational actions and under conditions of exercise, without notching some type of formal integrity;
b) to mitigate the effects of vibrating actions produced by anthropogenic conditions (vibrating cars, trains, etc.);
c) to realize hydraulic barriers of great efficiency and reliability in presence of polluting agents also.

The searches developed actually to today they have in fact underlined that it follows:

- for objectives a) and b): it is sensitively possible to demolish the propagation of cut waves (whence produced by anthropogenic or seismic rising) introducing in the groud poles of nanotech material with performance physical-mechanics with different those of natural ground. Particularly, idea consists in the introduction of a relatively thin layer of material characterized by a lower dynamic impedance of that of surrounding ground. The numerical analyses and the laboratory tests effected have shown that, when the relationship between the impedance of natural ground and material that make the barrier to vibrations reaches values of 20-30, barriers geometrically well assemble allow a demolition of propagation of the vibrations[1]. The activities of search in the circle of the technology applied to geotechnical engineering and the structural design have allowed to find the optimal geometric configurations, that differ in operation some considered (mitigation of seismic risk or by vibrations of anthropogenic nature) source. This has allowed to identify some material nanotech fit to the appointed purpose. Although searches have been effected on original material also, the existence is verified eco-friendly products (such that is to be able to be introduced in the ground without polluting and to cause environmental damages) is verified by to be able to use with great simplicity and with economic convenience. For this application, it will be considered also the possibility of addimixture the injections so that to make the porous columns, with the purpose to reduce the density of material (beneficent dynamic effect) and to increase the hydraulic permeability of barrier, to make this application not disturbs the underground waters system.

- for objective c): it is verified that the materials studied at last to satisfy the objectives a) and b) they could be also proper to the satisfaction of same objective. As written in precedence, in fact, the demolition of vibrations must be gets with a material that it am possibly light but that has, above all, low speed of the cut waves and it is therefore very deformable. The materials that have been identified with these characteristics can have put in work with composition slightly modified for giving columns place with practically void permeability, very deformable.

It is interesting to observe that the whole of possible applications is ample and that jet grouting technology must be conceive as mix by a chemistry component of base, water and ground eventually, with operation varying percentages for specific application to be resolved. In other words, the product that proposes it will be adaptable to different demands in simple way through a change percentage of components of base and therefore with nanotech performance.
Such technology is absolutely innovative both in the field of the defense from the vibrations both in that for environmental defense. For first application, particularly, the seismic isolation of existing buildings is a unsolved problem and, in fact, usually it intervenes reducing the vulnerability by interventions on structures with character of invasiveness and being particularly expensive. With particular reference then to structures of merit, that characterize italian architectural heritage patrimony, the traditional technologies for reduction of seismic vulnerability must be such not jeopardized the historical and material integrity of structure to protect and it must guarantee reversibility of applications. This can make the intervention on merit structures complex particularly.

With reference to risk mitigation the developed technology can represent a reliable solution for seismic adjustment of merit or strategic existing buildings in case of natural event. In such sense, the benefits it depend from the durability of effectiveness of the solution and the possible controls. The consequent benefits from the application of the column isolation, both in term of cost of life cycle attended and for terms of characteristics of global performance of the structures, it esteems can engrave with a 30% reduction of work costs. With reference to the strategic interest structures it is possible to get a great reduction of costs if account of post-earthquake use.

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 is tied to concrete composition, loads and maturation. It can be affirmed as nanotech concrete realized with an opportune mix-design and made to mature in pre-arranged times it can make less influential such negative influence of rheological factors by high resistant to loads. This is directly influenced by the workability that it constitutes the most complex performance to consider to the fresh state. It is not possible to characterize the workability with a numerical parameter but the studies already performed they allow to affirm whether to frame the connected phenomena to the workability needs to follow the rules of the rheology staying defined the characteristic parameters how the inside attrition coefficient and the cohesion [De Sivo, Cito, Iovino, Irace, 1987]. The best workability influences the value of the porosity and, therefore, of the compactness. Faury verified that in an unitary volume of fresh concrete porosity can be calculated with the expression:

$$I = \frac{K}{\sqrt[5]{Dmax}} + \frac{K\prime}{\frac{\rho}{Dmax} - 0{,}75}$$

where:

ρ = mean radius of the shuttering
Dmax = 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’

Using, therefore, nanotech concretes are gotten reduced values of I in operation mainly of the value of K. Always in the circle of the rules of the technology in seismic zone, within the local structural interventions, the technique of the nanotech concrete jacket can achieve all or some of the followings objective:

- increase of the vertical strength ability;
- increase of bending or cut resistance;
- increase of deformation ability.

The thickness of the local intervention must be such to be allowed the positioning of longitudinal and transversal armors. For evaluation of the resistance and the deformation of structural elements they are acceptable the following simplification hypotheses [Catalano, 2016]:

- the structural element involves monolithically with full adherence between old and new concrete;
- the fact neglects that the axial load is applied to the alone preexisting element and it is considered that it acts on the whole section;
- the mechanical performances of the concrete are considered wide to the whole section if the differences among the two materials are not excessive.

The values of performances to be adopted in the verification are calculated by reference to the structural section in the on simplification hypotheses redoubts according following expression:

- shear strength resistance: V = 0.9 V
- bending resistance: M =0.9 M
- yeld strength: θy = 0.9 θy
- final deformation: θu = θu

Notes

1. General characteristics of dynamic interaction ground-structure by method of impedance dynamics functions are:
- general methodology to define the dynamic answer of a foundation;
- assimilation the system ground-foundation to assembled masses system;
- hypothesis of harmonic vibrations system;
- easily generalizable to vibrations not harmonicas with Fourier theorem;
- development of calculation codes for more common foundations.

REFERENCES

- Carpani B., [2017], “Base isolation from a historical perspective”, 16th World Conference on Earthquake, Santiago Chile
- Clemente P., [2017], “Seismic isolation: past, present and the importance of SHM for the future”
- Catalano A., [2016], “La tecnologia per la buona regola costruttiva antisismica”, INGENIO n.49
- Lai C.G., [2011], “Interazione dinamica terreno-struttura di edifici con fondazioni superficiali e profonde”, Corso di aggiornamento avanzato sulla Geotecnica, La Spezia
- De Sivo B., Cito G., Iovino R., Irace A., [1987], “Appunti di Architetture tecnica”, Napoli
- Reithel A., [1964], “Costruzione di ponti”, Napoli