Research for a road engineering structure surface quality indicator

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Synopsis

The current indicators of the condition of a road engineering structure are based on a system of visual inspections. These indicators do not take account of decay in the internal layers of the elements of the engineering structure. The paper analyses the measurements obtainable with physical parameters, determined during the course of thermographic, georadar and tomographic investigations and applied to road engineering structures.

The indicators of the parameters referred to each type of investigation may then be aggregated in a single indicator, which expresses the overall measurement carried out and allows the maintenance of the road engineering structures to be programmed.

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In the current economic context, the construction or reconstruction of infrastructures have economic financing limitations due to the lack of available resources. Planning maintenance of roads, superstructures and in particular engineering works has thus acquired significant importance and thus the non destructive investigations aimed at defining the current state of decay of the structures have acquired significance.

Moreover, engineering structures are subject to traffic increases and increases in the transiting loads compared to the periods when they were designed, as well as to chemical – physical aggression from environmental elements.
At the moment, monitoring engineering structures is fundamentally based on visual inspections in almost all the countries belonging to the AIPCR "World Road Association", whose analysis criteria are established in the following three documents:
OECD documents of 1976 "Control of road engineering structures" and of 1992 "Bridge management"
AIPCR document date 1996 "Vers un indicateur de l'ètat des ponts / Towards an indicator of the health condition of bridges"
AIPCR questionnaire dated 11/12/2001.

However, the type of inspection and frequency of inspection vary from country to country but generally depend on the state of preservation, the importance, the age and the type of structure.

VISUAL INDICATORS OF DECAY

The current indicators of the condition of an engineering structure are based on a system of visual inspections. The inspections concern individual elements of the engineering structure. Both structural elements and non structural elements are investigated. The former have a function of bearing and structural safety of the engineering structure, like abutment, piers, longitudinal beams, traverses, decks, resting equipment and anti-seismic devices, the latter do not have functions of resistance but only of safety and durability of the structure, like joints, waterproofing membrane, surface, guard-rail, pavement and railings.

The inspections consist of topographic and photographic surveys of all the elements which show the state of deterioration of each component.

The information acquired is processed by associating any defect found and their causes. In this way a value of condition is defined for each element, expressing the efficiency of the element. This value is then converted into a condition factor. A combination of the factors of each element is used to determine the design level of the engineering structure, giving each element a different weight for the functions carried out in the whole structure. The design level refers to the management of the individual structure. With the same logic, in managing a network, it is possible to give a different weight of the structure compared to the other ones in the same network, defined by the type of road to which the engineering structure belongs, by the traffic crossing the bridge, by the inconvenience of its closure and by its age.

THE CURRENT NON DESTRUCTIVE INVESTIGATION METHODS

At the current moment, in order to obtain a precise evaluation of the state of decay of a road engineering structure by means of non destructive methodologies, it is necessary to use different techniques in an integrated manner and in the order reported in Luizzi R. - "Caratteristiche di degrado delle opere d'arte stradali" (Decay characteristics of road engineering works) - Le Strade 06/2004:
visual investigation, to check the overall situation in the visible field and to determine any objects on the surface of the investigated elements, which can give rise to false signals in the thermographic results;
thermographic investigation, to provide results with the general state of decay of the investigated element;
georadar investigation, to be carried out in the areas that the thermographic investigation show to have a particular situation which must be studied further;
tomographic investigation, to analyse in detail particular outcomes of interest found by the vision of the radargram.

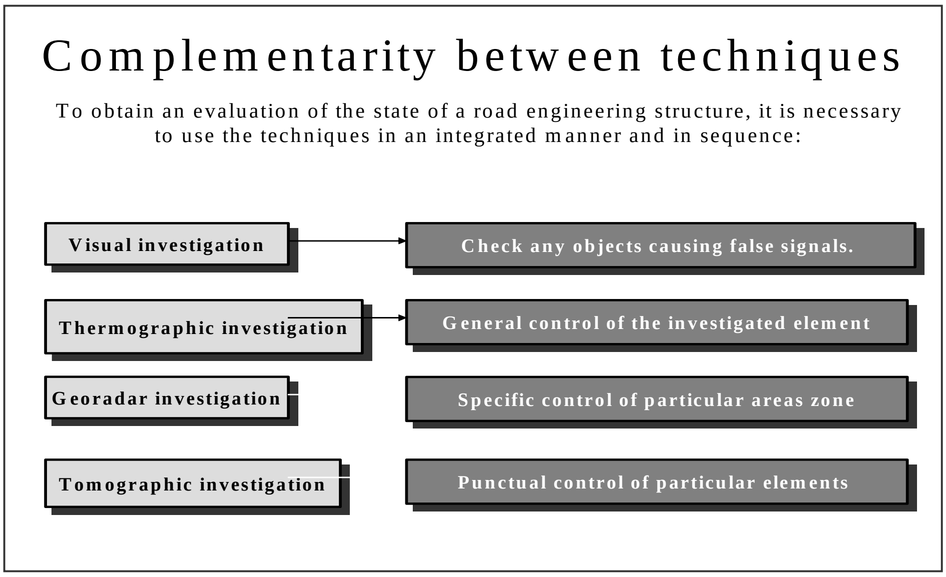

Figure 1: Sequence of investigations on the state of an engineering structure

The visual investigation allows the surface status of the individual elements of the engineering structure to be determined and create a data base on the current status of the engineering structure

The thermographic investigation on the other hand shows the temperature differences on the surface of the bridge between healthy zones and zones with delamination. These differences are called “heat anomalies” Heat anomalies are represented with thermograms of the bridge, in which the delaminated areas are shown with a whitey-grey colour with a black background which indicates healthy concrete. It is of course also possible to measure the percentage of surface delamination on the thermograms compared to the total area of the investigated element. Vertical cracks can also be represented with thermograms and highlighted with different colours, like red, compared to the remaining delamination.
Thermography also makes it possible to use those thermal type physical quantitative models reported in Kenneth R. Maser and W.M. Kim Roddis – “Principles of thermography and radar for bridge deck assessment” – Journal of trasportation engineering vol. 116, no.5 September/October, 1990, to determine the thicknesses of the covering layer of concrete, of the delamination layer and of the healthy layer of concrete underneath. The delaminated layer is a damaged area with modified thermal properties. The thermal effect of this delaminated area is assumed to be equivalent to a horizontal sheet with an even thickness which contains fissures full of air or water.

According to the model of Kenneth R. Maser and W.M. Kim Roddis heat conductivity k_d, specific heat v_d and thickness d_d of the damaged layer can be defined on the basis of this equivalent assumed fissure.

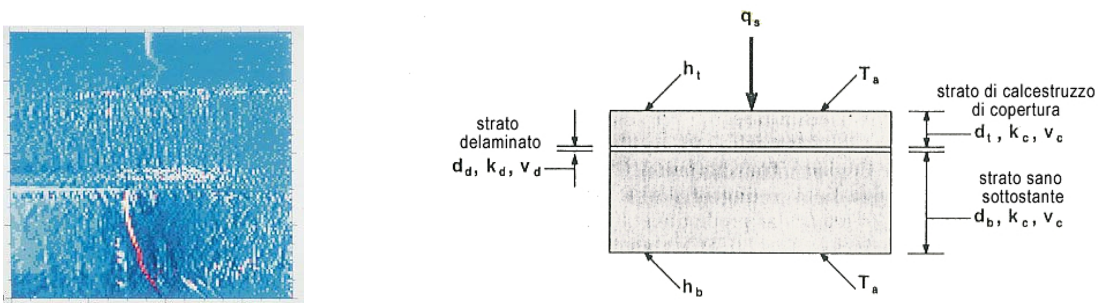

Figure 2: Thermal model of bridge element

The georadar investigation also allows a radargram to be returned which makes it possible to distinguish areas of delaminated concrete from healthy concrete areas and delaminated areas with air pockets from delaminated areas with the presence of moisture or chlorides using different colours. In the typical representation, the various colours represent different conditions of the material with different dielectric constants. A colour is associated to each material defect: Particularly, light blue lines represents gaps in the concrete, which fill with air, whereas red coloured spaces represent healthy concrete.

For a more quantitative study, a model can be used, which considers the engineering structure as a multilayer structure with cylindrical inserts like the metal mesh. The layers of the engineering structure are the surface layer of bituminous mix, the covering layer of aggregate concrete, the delamination and the remaining concrete. Each layer of the model is assigned a relative dielectric constant ε_r and a conductivity σ. The propagation speed of the radar signal and the attenuation in each structure can be calculated by means of this property.

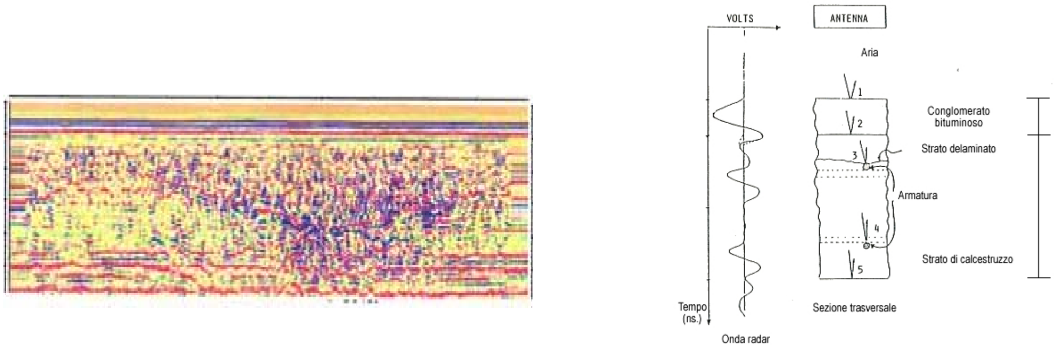

Figure 3: Georadar model of a bridge element

Finally, sonic tomography evaluates the propagation speed variation of the elastic waves inside a structural element by means of a series of sonic or ultrasonic measures carried out on the perimeter of the investigated area. The technique, thus, allows evaluation of physical characteristics like homogeneousness, density, consistency, the presence of defects in the structure. It permits a virtual reconstruction of the position and of the extension of internal stratigraphic discontinuity by processing mapping of isovelocities called tomograms.

In particular the tomographic measures consist of stressing the material with a series of compression waves and of determining the response of the element in terms of wave propagation speed. The stress and the determination of the responses occur along the perimeter of the flat section of the element investigated so that a grid of propagation routes is created inside the section itself.
Processing the responses is above all carried out with an analysis of the determined signals in order to evaluate the propagation times required by the signals themselves to perform the single routes and to consequently calculate the propagation speed of the impulses in the material, as the length of the routes is known. The real tomographical analysis is then carried out in order to evaluate the range of the speed values inside the section of the investigated element and to determine the position and extent of stratigraphic discontinuities, gaps and fissures. The final result of processing consists of signal propagation speed maps which allow any anomalies present in the investigated sections to be determined. The speeds are correlated to a colour variation scale, in which the cool tones (light blue) correspond to low speed values, vice versa, warm tones (reds) correspond to high speed values. Continual speed changes in the tomograms generally indicate high heterogeneity in the materials with the possible presence of gaps and fissures. Large areas with completely different speed values indicate changes of the physical-mechanical characteristics of the materials making up the section: generally, higher speeds correspond to better mechanical characteristics.

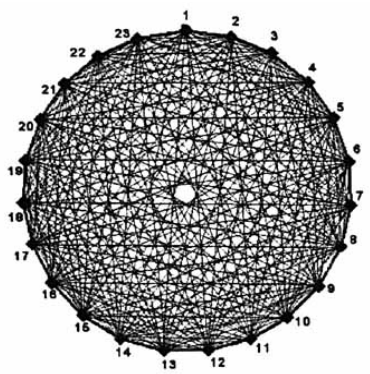

Figure 4: Tomographic model of a bridge element

THERMOGRAPHIC, RADARGRAPHIC AND TOMOGRAPHIC INDICATORS

Methods currently used in civil engineering, which are recently approaching the road engineering works sector, allow technical parameters, which determine and rationalise degradation phenomena of road engineering structures, to be measured. They can be summarised as follows:

Thermographic investigations

S_t^d = delaminated surfaces

S_t^t = total area of the investigated element

d_t^d = thickness of the delaminated layer

d_t^t = total thickness of the investigated element

h_d^t = depth of the delaminated layer

K_t^d = thermal conductibility of the delaminated layer

K_t^s = thermal conductibility of the healthy layer

Georadar investigations

S_d^g = delaminated surface

S_t^g = total area of the investigated element

d_d^g = thickness of the delaminated layer

d_t^g = total thickness of the investigated element

h_d^g = depth of the delaminated layer

ε_g^d = dielectric constant of the delaminated layer

ε_g^s = dielectric constant of the healthy layer

Tomographic investigations

v_m^t = mean propagation speed of the elastic waves in the investigated element

v_s = mean propagation speed of the elastic waves in the healthy element

These parameters allow new decay status indices of the engineering works to be proposed:

$$i_t^s = S_t^d \Big/ S_t^t$$

which express the percentage area of the road engineering structure investigated with thermography, subject to delamination;

$$i_g^s = S_g^d \Big/ S_g^t$$

which express the percentage area of the road engineering structure, investigated with georadar, subject to delamination;

$$i_g^s = d_t^d \Big/ d_t^t$$

which expresses the thickness of the delaminated layer referred to the total thickness of the element to which it belongs, analysed with thermographic investigations;

$$i_g^d = d_g^d \Big/ d_g^t$$

which expresses the thickness of the delaminated layer referred to the total thickness of the element to which it belongs, analysed with georadar investigations;

$$i_t^h = h_t^d \Big/ d_t^t$$

which expresses the relevant position of the delaminated layer referred to the total thickness of the element to which it belongs, analysed with technographic investigations;

$$i_g^h = h_g^d \big/ d_g^t$$

which expresses the relevant position of the delaminated layer referred to the total thickness of the element to which it belongs, analysed with georadar investigations;

$$i_t^k = k_t^d \big/ k_t^s$$

which expresses the rate of decay of the delaminated layer compared to the healthy layer in terms of thermal conductibility;

$$i_g^\varepsilon = \varepsilon_g^d \big/ \varepsilon_g^s$$

which expresses the rate of decay of the delaminated layer compared to the healthy layer in terms of dielectric constant;

$$i_{t\mathrm{om}}^v = v_n \big/ v_s$$

which expresses the rate of decay of the delaminated layer compared to the healthy layer in terms of propagation speed of the elastic waves.

AGGREGATE QUALITY INDICATOR OF AN ENGINEERING STRUCTURE

The previously defined indicators express different measurements of the state of decay of a road engineering structure, like the level of delaminated area compared to the total area, the relation between delaminated thickness and total thickness, the relevant depth of the delaminated layer compared to the total and the quality of the delaminated layer.

For each type of thermographic, georadar and tomographic investigation an aggregate index of the described characteristics can be defined as a quality level of the engineering structure.

The global quality indicator can be determined by means of a mathematic relation, a function of the described indices of the following type:

$$I_{agg} = f\left(I_1, I_2, \ldots I_n\right)$$

where
I_{agg} = indicator of global quality
$I_1, I_2, \ldots I_n$ = partial indicators
f = function between partial indicators and global indicator

The above mentioned function may be written in the specific case of the thermograhic investigations:

$$I_{agg} = p_1^t i_t^S + p_2^t i_t^d + p_3^t i_t^h + p_4^t i_t^K$$

and in the specific case of the georadar investigations:

$$I_{agg}^g = p_1^g i_g^S + p_2^g i_g^d + p_3 i_g^h + p_4 i_g^E$$

where

p_i^t and p_i^g are weights to attribute to the single factors *s* of area, *d* of thickness of the delaminated layer*, h* of depth of the delaminated layer, *k* of heat conductibility and *s* of dielectric constant of the delaminated layer.

It is a question of giving I_{agg}^{t} and I_{agg}^{g} values of programming indices in relevant comparisons between engineering works. Having defined the weights to give the surface area or the volumetric extension of the delamination phenomena, or even the level of decay of the delaminated layer, the comparison between indicators of different engineering structures is homogeneous.

Finally, it should be said that the index $i_{t\mathrm{om}}^{v}$ may determine the quality of the delaminated layer as an alternative to that of i_{t}^{k} and of i_{g}^{ε} and, thus, may enter in I_{agg}^{t} or in I_{agg}^{g} in their place.

CONCLUSIONS

At the current moment planning road engineering structure maintenance is carried out on the basis of visual investigations and of indicators based on parameters whose measurements are determined visually. The limit of these types of investigation are basically firstly that of not considering, in the indicators, decay phenomenon existing in the internal layers of the engineering works, whose fissures cannot be determined on the surface, then that it is not possible to establish the depth of the delaminated layers in the transversal context of the investigated element, finally, that there is no measurement of the quality of the delaminated layers in the visual indicators and thus of their level of decay.

Equipment already used in the sectors of civil engineering can permit measurement of the parameters indirectly from measurements of physical parameters, determined during the course of thermographic, georadar and tomographic investigations

The representative characteristics of the decay phenomena and their correspondence with the physical parameters of the three indicated methodologies have been determined. Standardisation of these parameters was carried out by relating the measurements referred to the delaminated layers to the total measurements.

Subsequently, the indicators of the different parameters referred to each type of investigation can be joined in a single aggregate indicator which expresses the overall measurement carried out respectively with thermography, with the georadar or with the tomography.

Planning maintenance may be based on these indicators: an investigation hierarchy may be in this order: firstly visual, then thermographic, then georadar and finally tomography, thus following a sequence of investigation from general to particular.

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