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Measures for Maintenance of Concrete Structures

Mesures à prendre pour la maintenance des structures en béton

Massnahmen für die Unterhaltung von Betonbauwerken

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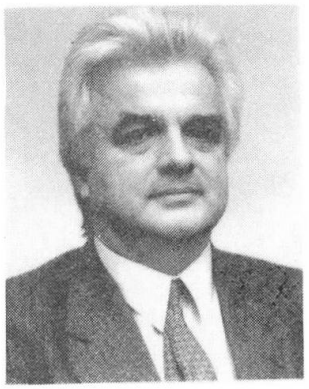

Aleksandar Pakvor was born in 1934. B. Civ. Eng. , Master of Engineering and Doctor of Science from the University of Belgrade. After five-years' work at the Institute CERNI in Belgrade, he started working at the Belgrade University. As Professor for Concrete Structures he is engaged in teaching, scientific, research work and professional activities.

SUMMARY

Provision of sufficient safety, the necessary serviceability and the required durability of concrete structures during the service life is both a technical and an economic problem. Maintenance of existing concrete structures requires considerable financial resources. On the basis of experience, the improvement of concrete structures' quality and the reduction of maintenance expenses provide the most convenient solution. For easy and economic maintenance, a series of measures should be taken during design, construction, exploitation and maintenance. Regular and preventive maintenance, systematically organized with planned financing, has many advantages.

RÉSUMÉ

L'assurance d'une sécurité et d'une durabilité suffisantes des structures en béton en cours d'exploitation est un problème technique et économique. La maintenance des structures existantes exige des moyens financiers importants. D'après les expériences faites jusqu'à présent, l'amélioration de la qualité de futures structures en béton et la diminution des frais de maintenance constituent la solution la plus favorable. Pour une maintenance facile et économique, il faut prendre une série de mesures lors du projet, de l'exécution, de l'exploitation et de la maintenance même. L'avantage est donné à une maintenance régulière et préventive qui est systématiquement organisée et financièrement planifiée.

ZUSAMMENFASSUNG

Die Garantie genügender Sicherheit, nötiger Gebrauchsfähigkeit und geforderter Dauerhaftigkeit von Betonbauwerken im Laufe ihrer Anwendung ist ein technisches und ein wirtschaftliches Problem. Die Unterhaltung bestehender Bauwerke fordert merkliche finanzielle Mittel. Den bisherigen Erfahrungen nach ist eine Qualitätsverbesserung von Betonbauwerken und eine Verringerung der Unterhaltungskosten die günstigste Lösung. Für eine leichte und wirtschaftliche Unterhaltung sind zahlreiche Massnahmen erforderlich : beim Entwurf, der Ausführung, der Anwendung und der Unterhaltung selbst. Den Vorrang hat eine regelmässige und eine präventive Unterhaltung, die systematisch organisiert und planmässig finanziert ist.

Nowadays, when concrete structures are widely applied in civil engineering, their *maintenance* has become a very present *technical* and *economic* problem. Recently, sudden unexpected catastrophies of failure due to poor maintenance have been witnessed and, on the other hand, considerable financial resources are required for the maintenance of the existing concrete structures. Great interest of experts in this field is not accidental, neither are numerous professional and detailed discussions on a series of scientific and professional conferences. When selecting the most convenient solutions for the new concrete structures, in the process of comparing the possible alternatives, care must be taken on the anticipated future maintenance costs.

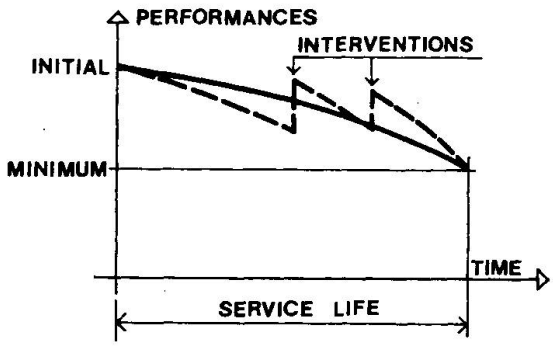

Fig. 1. SERVICE LIFE OF CONCRETE STRUCTURES

The designed *service life* of concrete structures can be achieved with different scope of interventions Fig. 1. The better the quality of the concrete structures, the lower the decrease of their performances from the initial to the minimum required values at the end of the service life. More frequent interventions are necessary to make the service life of the lower quality concrete structures match the service life of the higher quality concrete structures. That certainly requires higher expenses.

Due to technical and economic reasons there should be a tenedency to make the future concrete structures of the *best quality* possible, to make *maintenance operations easy* with the *minimum expences*. Beside correcting the designing, construction, exploitation and maintenance defects and errors, many future inovations will be necessary in order to increase the quality of concrete structures.

The very fact that the requirements with regard to the safety and serviceability of the concrete structures are most frequently increased during the exploitation period makes it difficult to establish the required service life. When designing, it is not easy to realistically establish, many years in advance, all future requirements connected with the increase of loading and actions together with technological and functional requirements.

It is quite clear that concrete structures, when they reach their service life, *should not be immediately replaced*. That is, however, the moment when it should be *analyzed* and *assessed* if the future increased expenses of the maintenance would be *economically more favourable* than the expenses of building a new structure. That is when *the decision should be made on further destiny* of the existing concrete structures.

Maintenance should cover *all the elements of the strucutures* regardless of whether those elements, in the strict sense of the word, belong to the concrete structures themselves or not. Poor maintenance of the *equipment* of the structures can greatly influence the decrease of concrete structures reliability. As such equipment is, as a rule, of *significantly lower durability*, great attention must be paid to its maintenance. *Control, repair, rehabilitation* and *replacement* of the equipment should be much *more frequent*.

It is extremely important that all the elements of concrete structures and of the equipment are absolutely *accessible* for control and interventions. This especially refers to the parts which are subjected to great stresses or to stresses which are difficult to be precisely anticipated including the parts exposed to aggressive actions. The easiest possible replacement should be provided for the lower durability elements of the equipment. This should be taken care of already during the stage of designing. Special attention must be paid to those elements of the concrete structures which must remain difficult to access.

Maintenance of concrete structures should be *regular* and *preventive*. Irregular

maintenance, especially if it is initiated by the damages which are, when observed, in most cases, in an advanced stage, causes far greater total expenses.

The maintenance of concrete structures and of the equipment depends on a series of technical and economic factors. In order to make the maintenance *easy* and *economical a series of measures* should be taken at *designing, construction, exploitation* and the *maintenance* itself. The specific measures depend on the basic *purposes of the maintenance*: to achieve *safety, serviceability* and *durability*.

The first group of measures refers to securing the sufficient *safety* of concrete structures during their service life.

The real *safety factor* of the concrete structures in relation to the ultimate limit state should correspond to the prescribed *limit values*. At the design stage, on the basis of the real data regarding the location, loadings and the possible action with the introduction of the realistic properties of the applied materials, the expected values of the safety factors, should be determined as precisely as possible. Attention should be paid to the selection of geometrical forms and the details to be constructed. Concrete structures should be of simple shapes, not too indented, and filgree forms, they should not include sudden changes of geometrical forms, the distribution of reinforcement and tendons should enable regular casting of concrete. There should be no high concentration of reinforcement but the concrete should be sufficiently filled with reinforcement especially on the places on which tendons are anchored and the places subjected to the action of concentrated forces. During the construction stage, it is necessary to fully attain the requirements of the design especially with regard to the materials used and the executed works, with regard to the preciseness of geometrical form including the position of tendons and reinforcement, with regard to the boundary conditions and the way of the loading transmission. If possible, during the exploitation, it is necessary to protect the structure from overload and unforseen actions especially if they are uncontrolled. During the maintenance, it is necessary to control and prevent all changes that could cause decrease of the safety factor below the permitted values. It is also necessary to control bearings, expansion joints, displacements of supports, uneven settlements, scour of the foundations, damages and unevenness of the pavements damages of thermal insulations and the like. Supplementary analyses of real safety factors is indispensable in cases of changes which are difficult to prevent. If required, rehabilitation of the structure should be done.

The second group of measures refers to securing the necessary *serviceability* of concrete structures and the equipment during the service life.

Real *defelctions*, and *widths of the cracks* and *vibrations* of concrete structures should correspond to the coded or adopted *limit values*. Thereby, the required function is provided together with the influence on *durability, aesthetics* and *psychological safety* . During designing, the expected values of deflections, widths of cracks and vibrations should be determined with maximum preciseness. Concentrations of stresses and unforseen cracks, should be avoided by the application of the corresponding construction measures. During maintenance, the real deflections, the widths of the cracks and vibrations should be controlled. If they are not within the design limits the causes of the excess should be immediately established and removed together with injecting of all cracks of excessive width and, if necessary, the rehabilitation.

During designing, construction, exploitation and maintenance, a series of measures should be taken to provide *serviceability* of the equipment of the structure. Its correct functioning could significantly influence the serviceability of concrete structure.

The third group of measures refers to the provision of the required *durability* of concrete structures.

The required measures are related to prevention, decrease or slowing down the

deterioration processes in concrete structures as well as to the repairs and rehabilitation of the damages.

The most serious form of the concrete structures deterioration is the *deterioration of steel* arising due to the *corrosion of reinforcement* and the *corrosion of tendons*. Full attention must be paid to the permanent corrosion protection of the steel. In concrete, steel bars are corrosion protected by *passivation*. Due to the decrease of alkalinity of concrete, because of carbonation or environmental aggressivity, the passive oxide film on the surface of the steel bars becomes unstable and its dissolution takes place. Due to depassivation the corrosion protection of steel bars in disturbed.

Deterioration of concrete which can be *physical*, *chemical* or *biological* is less frequent compared with deterioration of steel. However, deterioration of concrete can significantly influence the increase of deterioration of steel.

Deterioration of concrete structures is highly influenced by the processes of the *combined transport of moisture, heat and chemical substances* within the concrete itself and in the interaction with the environment.

The presence of *water* and *moisture* in concrete structures during the service life is the most dangerous factor for the appearance and development of the deterioration processes. In order to increase durability, all measures should be taken to decrease or prevent retaining of water on concrete structures and its penetration into the concrete. Water should be drained off the concrete as soon as possible. Therefore, secure *waterproofing* and efficient *draining system* should be designed. When selecting the shape of the concrete structures, the possibilities of direct course or water retention on the surface of concrete should be avoided, especially on the places on which elements are connected and on the operation joints. Smooth concrete surfaces are better that the rough ones. Concrete should be protected from direct splashing especially when it is caused by traffic of vehicles due to possible presence deicing salt. Easy replacement should be designed for those elements which are difficult to protect. Openings for quick draining of possibly penetrated water should be designed on box girders together with the aeration of the boxes. The draining system should be so designed as to provide safe and quick draining of water and to be easily accessible for maintenance. The tubes should not be embedded into the concrete. During maintenance, permanent control of waterproofing and of draining system should be conducted. Possible damages or blocking of the draining system should be immediately removed. The drifted trash, dirt, dust and weeds should be regularly removed from the concrete structures.

The deterioration processes of concrete structures are significantly influenced by the *environmental aggressivity*. In most cases, concrete structures are placed in *chloride* aggressive environment due to presence of sea-salt on coastal structures or deicing salt on structures intendend for traffic. Industrial concrete structures can frequently be subjected to *chemical action* of various *aggressive substances*. During the designing and construction, measures of permanent protection against environmental aggressivity should be taken; during exploitation, measures directed to decrease environmental aggressivity should be applied ; the maintenance should include control and repair of the existing protective coatings and covers together with the removal of the drifted aggressive substances.

Climate conditions also make one of the factors of concrete structures deterioration. *Rainfall*, *snowfall* and *air humidity* are the main sources of possible water and moisture in concrete structures. The *increased temperature* influences the acceleration of the concrete deterioration processes. *Considerable temperature differences* that cannot be forseen can cause cracks in concrete while *thermal shocks* due to freezing and possible short-term fire can damage the concrete cover. Wind drifts drops of sea water or sea-salt sedimented on the coast to coastal concrete structures. *Rainfall* and *wind* together with dust and dirt can cause erosion of the concrete surface and they can block the draining systems. Beside already

listed measure, *thermal insulation* should be designed, following the requirements. It should be controlled and repaired during the maintenance of the structures.

The state of *concrete cover* and the state of *tendon protection* which is most frequently achieved by cement grouting make an essential factor of the concrete structures deterioration. Porous, thin, poorly made and damaged concrete covers and porous, poorly made and on some places the missing groutings for tendons, directly influence the corrosion of reinforcement and tendons. The process is progressive as the corroded steel bars cause further damage of the concrete cover. During the designing and construction, the *compactness* and the required *thickness* of the concrete cover should be secured that are, depending on environmental aggressivity, defined by the codes. The groat should be compact and well applied along the whole length of the tendons. During maintenance, it is very important to control the existing concrete covers and the grout for tendons. The appearance of rust stains, calcium or water on the surface of the concrete, the appearance of blistering, separation and falling off of the concrete cover, require urgent establishment of the causes and degrees of damages and their removal.

The state of *cracks* is also an essential factor of concrete structures deterioration. In the cracked areas, the penetration of aggressive substances into the concrete is much easier and the process of concrete carbonation is more intensive. To secure durability of concrete structures it is necessary that the width of the cracks does not exceed the limited values defined by the codes which is achieved by already mentioned measures. Cracks of the lower width, frequently full of calcium, dirt and rust deposits, have significantly lower influence on the deterioration processes.

Carbonation of concrete is also one of the basic factors of concrete structures deterioration. The progress of carbonation process into the concrete is very slow and the level of concrete carbonation can be easily established by chemical indicators.

The maintenance of concrete structures should be *systematically organized* with the *planned financing*.

The *maintenance design* should, depending on the kind of the structure, its quality and the degree of danger, anticipate the required *measures of maintenance* to be applied to concrete structures and the equipment, reasonable *frequency* of the relevant works and the *responsibility* for their performance. However, it is difficult to anticipate all the details in advance, especially after accidental actions, the alteration of the exploitation conditions and the discovery of the unknown failures and errors made during the construction.

All the data on the anticipated and the realized maintenance make an integral part of *technical documentation* on each concrete structure and must be carefully taken care of.

The purpose of *organizational forms of maintenance* is to *establish the condition and behaviour* periodically or against the requirements or they can mean higher or lower *interventions*.

Initial observations should be permanent and do not require any particular professional skill. The basic purpose of initial observations is to provide *permanent general, visual follow up of the condition and behaviour* of the concrete structures and the equipment in order to reach *due observation of the arisen changes* and to take the necessary actions.

Routine inspections of concrete structures should be carried out periodically, after time intervals which are established in advance. It is thought that the most endangered concrete structures (the structures in aggressive environment, bridges) should be subjected to such inspections once a year. Routine inspections cover *professional visual control of the condition and behaviour* of concrete structure and the equipment.

Periodical inspections are less frequent compared with the routine inspections but they are more detailed and more comprehensive. It is thought that the most endangered concrete structures should be subjected to such inspections every five years. Periodical inspections include the *detailed professional visual control of the condition and behaviour* of the concrete structure and the equipment including the *control measurements* of the quantities required for the establishment of the real reliability of the concrete structure.

Special inspections are carried out only following the requirements. They are performed on the highest professional level, only by specialized professional organizations or institutes, in many cases using the services of experts.

Against requirements, various *special investigations* can be carried out in order to establish the causes or levels of damages.

Correcting of small defects are the smallest but not unimportant interventions (removal of scrap, mud, weeds, salt and aggressive substances, cleaning, washing, prodding free of the draining system ....). Special skill is most frequently not required for such operations. However, it is especially important to carry out such operations *in time*. Delyed removal even of smaller defects can initiate further progressive damages of concrete structures.

Repairs are applied when damages of the equipment or the elements of concrete structures are relatively small. They are performed by professional individuals or services. No special designs are necessary for repairs although the corresponding technical documentation can be made.

Rehabilitations are applied to larger damages of the equipment or the elements of concrete structure. They are carried out according to specially produced main designs which contain, on the ground of the established cause and level of the damages, the detailed elaboration of the methods for their correction. Such designs also indicate the ways of rehabilitation of the damaged equipment or the elements of the concrete structure.

Reconstructions are the greatest interventions on concrete structures. Often, they are connected with *adaptations* for which there are requirements regarding significant increase of static and dynamic loading and actions or the new functional and technological demands.

In case it is found necessary, the replacement the equipment or individual elements of the whole concrete structure takes place.

Finally, the *great importance of correct maintenance of concrete structures* should be emphasized once again. Regular and systematic maintenance is technically the most efficient and economically the most favourable solution. By the establishment of the changes of conditions and behaviour on time, as well as by due correcting of the observed deffects and damages, significant contribution is made to sufficient safety, necessary serviceability and the required durability of concrete structures.

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