SOME ASPECTS CONCERNING THE DURABILITY OF SERVICE AND DEVELOPMENT IN THE BUILDING SECTOR

Horea SANDI[1]

[1]Full Member of the Academy of Technical Sciences in Romania

Abstract: The paper is aimed to present some ideas on the connection between the strategies of development of a safe and reliable infrastruacture as a whole and the components pertaining to the built environment. After a brief look on the development of methods of structural mechanics and the theory of safety, a qualitative, summary, overview on some aspects of providing appropriate safety and durability to the components of the bulding stock is intended. Some general, qualitative, aspects are followed by an analytical approach to the macro-analysis of risk of engineering works as a whole, presentinng some basic relations, are dealt with. Some illustratve results of engineering interest concerning the recurrrence of wind action and of the seismic action are presented. Some summary conclusions are finally presented.
Keywords: safety, durability, recurence, risk analysis.

1. INTRODUCTION

Lasting development of the infrastructure represents obviously a precondition for a lasting development of the society as a whole. On the other hand, the building sector represents a vital component of the infrastructure. Therefore, the concern for a lasting development of the building sector represents, at its turn, a vital component of human activities. Since physical (mechanical) phenomena determine the performance of loadbearing components, which is critical for the ability of various works to serve their destination, the specific conditions from this view point require appropriate attention. Other conditions to be imposed to the performance of various works are of secondary importance.

Providing an appropriate durability to the various components of the buiding sector represents a complex task, because one must consider, in this general frame, the needs to avoid:

– loss of specific functionality;
– damage due to various actions, and, first of all;
– danger to human live.

These conditions were kept in view, under various conceptual frames and using various technological tools at hand,since the dawn of engineering activities. A brief look back makes it possible to mention some phases of development of the two main branches of engneering analyses, namely the calculations specific to applied mechanics (usually performed in a deterministic frame) and those specific to safety management (which are adding a probabilistic approach).

2. SOME QUALITATIVE CONSIDERATIONS

The development of engineering activities was concentrated in the more remote past on the physical phenomena. The direct experience and its interpretation revealed nevertheless the randomness (or impossibility of precise, deterministic, predictability) of factors on which the performance during service of various works depends and therefore, graduallly increasing attention was paid more recently to this aspect. By now, one may identfy two main branches of engineerng analyses referred to:

− one of them, devoted to the mechanical phenomena and
− the other one, devoted to safety and reliabilty analysis.

Of course, the design of new works as well as the evaluation of exsting ones, must tackle jointly the branches referred to.The factors referred to are especially the characteristics of actions applied to works and the eigen charateristics of works. A first attempt to develop a systematic approach to these complex tasks is due to the activity of Soviet researchers in developing the *limit state design method*, which was endorsed for practice in 1955, after a long period of research, in the system of design codes for civil engineering. The progress of engineering activities due to the endorsement and use of thelimit state method was recognized worldwide. Several national and international groups of researchers aimed to control of appropriateness of the limit state method and at its furtherdevelopment were organized, especially in Western Europe and in the USA, and this contributed to the gradual improvement of the verification of safety and reliability provided to the various works. These latter investigations led to the approach of what is currently called (mainly due to the American approach and studies) *performance based design.* Concepts like *safety, reliability* and *durability* were subject to in depth analysis and methods to provide them in preactice were further developed.

The engineering approach developed was concerned at its beginnings with the verification (at a *micro*,or *local*,scale) of resistance at some critical points, sections etc. On the other hand, the requirements raised by providing appropriate safety and reliability to structures as a whole and even to more complex systems of structures, appeared and required to be dealt with. Gradually, some verifications at a *macro* scale of works as a whole appeared. The verifications considering structures as a whole were developed first in a deterministic framework for problems concerning mechanical performance like stability, dynamic behaviour, sometimes under conditions of quite crude idealizations. On the other hand, the need to take into account the randomness of factors on which structural performance depends and the need to develop a kind of summary approach to the verification of complex works, under conditions of more or less severe damage, became obvious. This kind of approach, combining a holistic procedure with probabilistic concepts,led to the development and use of concepts like vulnerability, risk etc. These instruments of analysis were useful especially in order to get a view on the performance of groups or systems of works, as appropriate for estimatingthe situation of the builtt environment after disasters, like e.g. those due to earthquakes.

The need to develop a probabilistic approach to the task of providing the goals referred to was recognized and also applied to several specific problems, and this led initially to the idea of defining and determining distributions of several specific, significant parameters, dealt with as various *random variables*. Moreover, it turned out that specific *stochasticprocesses* have to be defined and dealt with too, especially in order to cope with the time dependence of some of the significant parameters considered. The need to calibrate some parameters specifying random variables or random functions of time did sometimes not lead to success, essentially due to the drastic limitationsof basic information at hand. The ways of using random variables in order to control the risks affecting a work did develop quite slowly. In fact, the limit state approach relied initially on a simplisticway to deal, called later on a *semi-probabilistic* approach, which used quantiles of some distrtibutions, and ignoring the need to control safety on the basis of appropriate convolutions. A handicap in the way of using probabilistic safety control wasrepresented also by the lack of sufficiently comprehensive basic data in order to convincingly calibrate the distributions intended to be used.

An approach (due somehow to dispear) to surpass such difficulties was represented by the relatively recent development of *neo deterministic approaches*,used e.g. in developing practical methods, fist rules included, to deal with seismic action and hazard.

Due to various difficulties raised by the intention to design rationally various works, like limitations to required input data, methodological difficulties and uncertainties, and lack of necessary time required by more consistent analyses, the use of heuristic approaches, usually referred to as *expert judgement*, was and is yet a frequently used approach to the reference parameters controlling the safety of various works. Expert judgement represents a relatively competent way to consider a summary of practical experience in the actual performance of some kinds of works. The *expert judgement* is a necessary approach, especially when there occurs a more or less obvious failure in the attempt of applying rational, consistent, calculations. This way of dealing is gradually replaced bythe trend to apply rational analyses, but is, and will be, for at least a long time in the future, not replaced by consistent rational analyses. A kind of applying rational analyses in practice is represented by postulating on the basis of expert judgement some reference data and by using rational approaches rather for interpolation between reference situations agreed upon,by groups of competent specialists, on the basis of expert judgement. It may be stated that the rules of design specified by codes are based on such a procedure. The trend of replacing such empirical or semi-empirical procedures exists, but will not be fully successful during previsible times.

The reasonable nominal safety level of a new work should be adopted in principle for a desired period of service. Note that the service capability of a new work is often affected by usually occurring actions (e.g. vibration due to the function of industrial equipment) and, more severely, by exceptional actions (e.g. strong seismic actions). The desired (or required) level of safety of various works represented in the past,and represents currentlytoo, a matter of debate at the level of various local, national or international fora. Adopting a decision in this field represents in principle a problem of *optimization* between the size of investment required and the heavy adverse effects to occur in case a work dealt with is underprotected and is consequently affected by the likelyhood of some kind of failure. On one hand, the researchers, conscious about the stake of avoiding failures or accidents opted usually for a high safety level and managed to gradually increase, especially after some severe accidents, the severity of design regulations. On the other hand, the investors and construction achievers, interested in immediate profit, fought for avoiding expensive investment. This latter position was sanctioned, not once, by life. A drastic example of the costs to society due to underprotection was due to the effects of the Mexico earthquake of 1985.09.19, when hundreds of taller buildings, nominally protected, collapsed. A convincing view on the need to provide an appropriate calibration of safety parameters was expressed, e.g., during a panel discussion organized in the frame of the 6-th International Conference on Structural Safety and Reliability (Innsbruck, 1993) with the title *How safe is safe enough ?* Specialists of various engineering branches, of economy etc. were unanimous in claming for a high degree of safety and argued in the sense that this is finally the most economical way of proceeding.

Some rehabilitation measures may be required in order to reduce increased risks due to these phenomena or events. A dramatic case in this sense occurred e.g. in Romania, due to the effects of the destructive Vrancea earthquake of 1977.03.04. The experience of the need of rehabilitation of an important part of the building stock occurred. The drastically limited results in solving this task of obvious social importance revealed dramatically the need to provide appropriate safety, reliability and durability when designing various works.

Specifying a reasonable service duration is not an easy task. Direct experience reveals the fact that, in case of keeping the desirable service conditions, a work will be often kept in service, even after the service duration specified initially elapsed. On the other hand, some decisions on urban modernization or on business development may lead to an early replacement of existing works, much earlier than the duration specified initally. Specifying a desired duration of service is thus a complex and often difficult task.

3. SOME ANALYTICAL DEVELOPMENTS

3.1. General

The developments presented previously were intended to represent a rather multi-sided look at the problematique of durability and serviceability of various components of the infrastructure. It is useful to take now into account some analytical considerations. These developments, conducted essentially at a *macro scale*, rely basically on the developments of [10], which concerned a way to analyze seismic risk at a macro level. The subsequent presentation is to some extent specific to the analysis of seismic risk affecting various infrastructure components, but they may be adapted quite easily to eventual other cases concerning the durability and serviceability of the infrastructure under other categories of risk.

3.2. Main entities considered in macroscopic risk analyses

The main entities considered in this frame are

−*ELEMENTS EXPOSED* (or *Elements at risk*):any categories of entities that represent a social value and could be affected due to the presence or incidence of actions considered. *Examples*: people, buildings, equipment.

−*EXPOSURE* (of some category of elements at risk): a measure of the degree to which a definite category of elements at risk is exposed. One can consider, for various situations, full or partial instantaneous, constant or variable exposure. *Examples*: full and constant exposure, as in the case of buildings, or partial and variable exposure, as in the case of presence of people in an assembly hall.

−*ACTIONS* (specific to the environmentand to a category of elements at risk): effects of specific categories of phenomena that can adversely affect elements at risk dealt with. *Examples*: deadweight of various components, wind pressure, seismic motion, effects of industrial equipment.

−*CONVERSION*(for some specific actions): determining the mode in which actions at source determine actions on some infrastructure components dealt with. *Examples*: conversion of basic wind speed considered into a system of forces applied to a building, conversion of seismic magnitude at earthquake source into ground motion intensity, acceleration etc.at a site of interest, considering specific laws of radiation / attenuation, effects of local site conditions etc.

−*HAZARD* (specific to elements at risk and actions considered): measure of likelihood of being present or of occurrence of a definite category of actions considered. *Examples*: wind hazard, earthquake hazard.

−*ADVERSE EFFECTS*: potential effects of action presence or incidence with respect to features of elements at risk. *Examples*: life losses or injuries, physical damage to some infrastructure components, losses due to harming of functionality.

−*VULNERABILITY*: a measure of expected adverse effects corresponding to some action presence at some specified intensity.

−*RISK*: (to some specified elements at risk): a measure of likelihood of being present, or of occurrence, of some definite category of adverse effects considered.

3.3. Quantifications of some entities referred to. Some basic relations

Looking back to the entities referred to, some of them can be characterized in quantitative terms (usually in probabilistic ones), while other ones can be characterized in qualitative terms only. Following developments concern quantifiable entities and are related to actions, vulnerability and risk. In order to keep following developments at a lower level of sophistication, some specific basic quantifications, referred in concrete terms to the actions, vulnerability and risk, are dealt with subsequently. The superscripts used symbolize: (q): actions; (v): vulnerability and (r): risk. In each case, the quantification of action intensity and of effects is presented in discrete terms. It is easy, of course, to convert the relations expressed in discrete terms into relations expressed in continuous terms.

The characteristics of actions will refer only to two basic cases concerning a *scalar* random variable Q (that can take values q), namely:

a) the case of permanent, constant, static loading, for which an appropriate model referred to is that of a distribution of a random variable;

b) the case of loading occurring at random time moments t_i, lasting for each case an infinitely short duration, for which an appropriate model referred to is a stationary, Poissonian, stochastic process.

The random variable Q can thus take the discrete values q_j (of course, if it is present).

In case (a), the basic characteristic of the distribution is represented by the probabilities of non-exceedance

$$F^{(q)}_j = P\ (Q \leq q_j) \tag{3.1}$$

while the probabilities of occurrence of a value q_j, $f^{(q)}_j = P\ (Q = q_j)$, are given by the relations

$$f^{(q)}_1 = F^{(q)}_1 \tag{3.2a}$$

$$f^{(q)}_j = F^{(q)}_j - F^{(q)}_{j-1} \qquad (j > 1) \tag{3.2b}$$

In case (b), the basic characteristic of the random process is represented by the expected number of cases of occurrence of values not less than q_j during a time interval of duration T, $N^{(q)}_j(T)$, while the expected number of cases of occurrence of a value q_j, $n^{(q)}_j(T)$, is given by the expressions

$$N^{(q)}_1(T) = n^{(q}_1\ (T) \tag{3.3a}$$

$$N^{(q}_j\ (T) = \Sigma_{j' \geq j} n^{(q)}_{j'}(T) \qquad (j > 1). \tag{3.3b}$$

The probabilities of m cases of occurrence of values $q \geq q_j$ during a time interval of duration T, denoted here $P^{(q)}_m(q_j, T)$, are given by the expression

$$P^{(q)}_m(q_j, T) = \exp\ [- N^{(q)}_j(T)].[N^{(q)}_j(T)]^m / m! \qquad (m = 0, 1, 2, \dots) \tag{3.4}$$

It may be easily checked that $\Sigma_m P^{(q)}_m(q_j, T) \equiv 1$, for any values ($q_j$, T).

In order to define vulnerability, the adverse effects of interest are to be quantified too in a convenient way. This can be done, in principle, by means of engineering analyses or by collecting field data about the performance of a definite category of works. Here again, a random scalar measure of these effects, D, will be dealt with on the basis of discretization into possible values d_k. The vulnerability of a system dealt with is defined in this frame by means of the system of conditional probabilities $p^{(v)}_{k//j}$ (which can be determined by statistical analysis of observation data or by appropriate engineering calculations).

The risk of occurrence of some adverse effects is to be characterized by the probabilities of occurrence $p^{(r)}_k$ in case the action generating the adverse effects is permanent and constant, and by the system of expected occurrence frequencies $n^{(r)}_k(T)$ in case of variable actions. In the first case, the system of probabilities $p^{(r)}_k(T)$ is to be determined by the convolution

$$p^{(r)}_k = \Sigma_j p^{(v)}_{k//j} f^{(q)}_j \tag{3.5}$$

while in the second case the system of expected occurrence frequencies is to be determined by the convolutions

$$n^{(r)}_k (T) = \Sigma_j\, p^{(v)}_{k//j}\, n^{(q)}_j (T) \tag{3.6}$$

3.4. Some illustrative data

The illustrative data presented concern some graphic presentations of characteristics of actions. These data offer a view of possible data formats as well as some information on the orders of their magnitude.

A first case considered concerns a presentation on wind hazard at the meteorological station of the City of Ploiești. The basic data used were obtained for the meteorological station of that city, for a time interval of 32 years, during which the specific recording equipment and techniques were kept the same. This means that the data presented are homogeneous and make it possible to carry out an appropriate statistical analysis. The dots of Fig. 3.1 represent the maximum values for groups of years, while the curve of the same figure represents a function lg N ($Q \geq q$, 1 yr.),

$$\lg N_Q(Q \geq q, T) = 0.002736 \times (1089 - q^2) - 1.5563 + \lg T, \tag{3.7a}$$

$$N_Q(Q \geq q, T) = 10\uparrow[0.002736 \times (1089 - q^2) - 1.5563 + \lg T]. \quad (\uparrow : \text{symbol of power}) \tag{3.7b}$$

The data of Fig. 3.2 represent the probability functions $P^{(q)}{}_1(q_j, T)$ derived on the basis of expression (3.4), for the time intervals T = 1, 10 and 100 years.

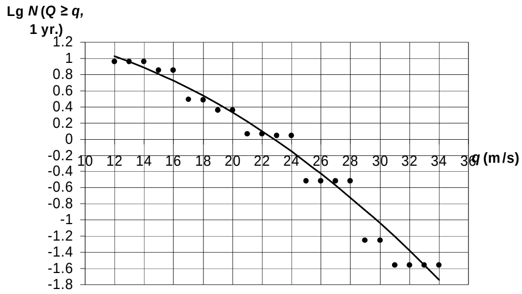

Fig. 3.1. Cumulated expected number of events (reduced to one year) and estimated recurrence characteristic lg$N$ ($Q \geq q$, 1 yr.) for wind speed in Ploieşti.

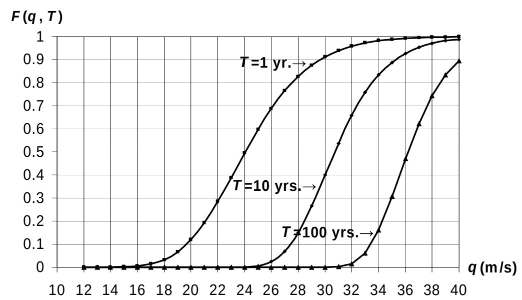

Fig. 3.2. Probability function of wind speed in Ploieşti for various exposure durations T, $F^{(S)}(q,T)$.

A second case dealt with concerns the statistics of M_{GR} (Gutenberg – Richter magnitudes), due to the activity of the Vrancea seismogenic zone for the twentieth century. The activity recorded during the 20-th century is represented in graphic terms (for $M_{GR} \geq 6.$), according to data of the catalog [3], updated, in Fig. 3.3.The recurrence of earthquakes of various magnitudes $M_{GR} \geq 6.$is represented (graphically too) in Fig. 3.4. Two alternative assumptions, on the maximum possible magnitudes, were considered in this connection.

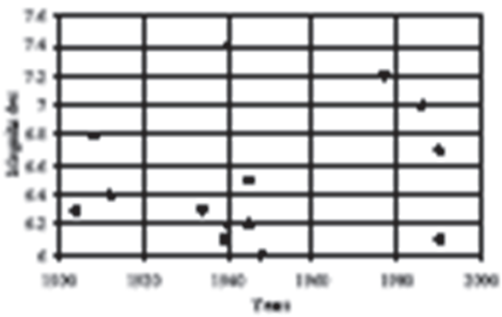

Fig. 3.3. Time history of Vrancea magnitudes M_{GR}, recurrence frequency during the twentieth century.

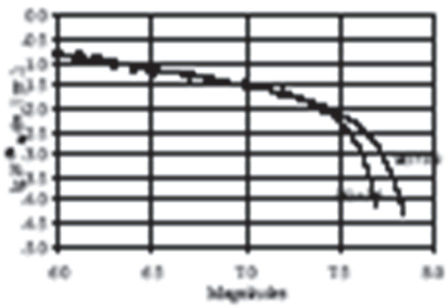

Fig. 3.4. Vrancea magnitude function lg*N* ($Q \geq q$, 1 yr.), under two alternative assumptions on maximum magnitude.

The alternative analytical expressions determined for the recurrence of magnitudes were: $m_{lim.} = 7.8$ and $m_{lim.} = 8.0$ respectively. The recurrence laws proposed were

$$\lg N_M(m,\ 1\ \text{yr.}) = 3.4 - 0.7\ m \qquad (6. \leq m < 7.) \qquad (3.8)$$

and, alternatively, for the two asymptotic branches of the figure,

$$\lg N_M(m,\ 1\ \text{yr.}) = 0.3 - 0.2\ m - 0.32\ /\ (7.8 - m) \qquad (7. \leq m < 7.8) \qquad (3.9)$$

$$\lg N_M(m,\ 1\ \text{yr.}) = 0.4 - 0.2\ m - 0.5\ /\ (8. - m) \qquad (7. \leq m < 8.0) \qquad (3.10)$$

4. CLOSING CONSIDERATIONS

The presentation of several aspects dealt with in the paper is by far not exhaustive. Nevertheless, it raises some problems that are specific to the field of civil engineering and puts to evidence some main instruments that are proper to engineering analyses concerning safety and durability of various works.

The analytical relations presented are specific to risk analysis at a macro scale for entities pertaining to the built environment. The approach presented can be, nevertheless, adapted to the analysis of other components of the infrastructure.

The references leading to the risk analysis presented in the paper concerned very simple cases of engineering interest, dealt with on the basis of an appropriate representation of the entities. The relations presented are based on a probabilistic philosophy. In practice, there will occur numerous cases when such an approach may be not fully feasible. The probabilistic approach to such cases should be nevertheless imagined, since this way may often, even when not applied directly, reveal some important facets of the technical problem dealt with and act as a guide to solving concrete problems.

The instruments used in performing analyses that are proper to this field were characterized by a continuous progress. On the other hand, any attempt of judging the state of the art reveals the need of research aimed at strengthening the ability of analysts to carry out their work. Research devoted to this field should be further on strengthened.

The progress in the field of IT, from the viewpoints of hardware and software both, was characterized by a fast pace. The ability of analysts to perform their tasks is limited at the same time by the current limits characterizing the IT. A critical look shows that analysis capabilities and data bases used in this field reveals that there exists yet a strong hunger to increase these capabilities.

The complexity of the tasks of determining further progress in this field raises the need to combine the specific research efforts of various countries. As in many other fields, this raises the need to stimulate cooperation at an international level up to favoring common management to research efforts.

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UNELE ASPECTE PRIVIND DURABILITATEA SERVICIULUI ȘI DEZVOLTĂRII ÎN SECTORUL CONSTRUCȚIILOR

Horea SANDI[1]

[1]Membru titular al Academiei de Ştiințe Tehnice din România

Rezumat: Asigurarea unei durabilități adecvate pentru diferitele componente ale sectorului construcțiilor reprezintă o sarcină complexă. O primă încercare de a dezvolta o abordare sistematică a acestor sarcini este datorată cercetătorilor sovietici prin dezvoltarea *metodei stărilor limită*, care a fost oficializată în 1955. Au fost organizate diferite grupuri de cercetare în vederea perfecționării abordării menționate. Aceste investigații au condus la o abordare denumită (datorită studiilor americane) *proiectarea bazată pe performanță*. Au fost definite concepte ca *siguranța* și *fiabilitatea*. A fost recunoscută și aplicată, o abordare probabilistică a sarcinii de a asigura realizarea acestor deziderate, iar aceasta a condus la definirea și determinarea distribuțiilor unor parametri specifici, ca diferite *variabile aleatoare*. S-a constatat că trebuie definite de asemenea și abordate diferite *procese stochastice*. O abordare în dorința de a depăși astfel de dificultăți a fost reprezentată de dezvoltarea *abordărilor neo-deterministe*, utilizate spre exemplu în dezvoltarea de metode practice de abordare a acțiunii seismice. De asemenea, *judecata de expert* constituie o abordare necesară, în special atunci când încercarea de utilizare a unor metode de calcul duce la nereușită. Nivelul dorit de siguranță pentru diferitele lucrări a reprezentat un subiect de dezbatere pentru diferite foruri naționale sau internaționale. Nivelul nominal de siguranță pentru o lucrare nouă ar trebui precizat, pentru o durată de exploatare dorită. Pentru a reduce riscurile implicate de astfel de fenomene sau evenimente, pot fi necesare măsuri de reabilitare. Un caz dramatic în acest sens s-a produs în România, datorită efectelor cutremurului vrâncean din 1977.03.04. Aceasta a generat experiența nevoii de reabilitare a unei părți importante a fondului construit.