BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Tomul LII (LVI), Fasc. 1–2, 2006
CONSTRUCŢII. ARHITECTURĂ

CURRENT STATE OF THE ART FOR EXISTING CRITICAL SYSTEMS IN URBAN SEISMIC AREA

BY

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The paper is structured in three main parts. In the first part, there is a classification of the critical systems existing in the urban background, which are part of an extremely urging informational infrastructure in case of a seismic event. The critical systems are identified as those systems whose malfunction may lead to disasters affecting the human being and the environment as well.

The second part focuses on the underground pipe networks, presenting at the same time, their classification into three categories of great importance in case of an earthquake, and last but not least, the final part contains the presentation of an analysis methodology of seismic behavior of the underground pipe networks, considered as part of the existing critical systems, in case of a seismic event in an urban area.

1. Introduction

1.1. Concept of Critical System

Critical system is an extremely important system existing in an urban area, whose operability during an emergency situation (*e.g.* seismic event) must be interrupted in order to prevent the loss of human lives, material damages or major impact on the environment.

A classification of the critical facilities system in case of an earthquake may be realized by taking into account the incorporation into such a category of some structures as well as of some structural or nonstructural elements.

A. *Important structures from the perspective of the intervention in case of a seism*: hospitals, police departments, fire departments, whose post-seismic intervention is imperative for saving human lives and for reducing the damages of a disaster.

B. *Important structures from the perspective of the number and categories of sheltered people*: kindergartens, schools, boarding schools, jails, etc.

C. *Utility nets*: major drinking water supplies, gas distribution, thermic agents, drainage.

D. *Complex systems*: systems which in case of seismic damage may lead to major explosions, affecting large areas, leading to losses of human lives, immense material damages, and important impact on the environment – nuclear facilities, thermic plants, gas stations, industrial buildings, technological networks that deal with various technological agents.

Taking into consideration this classification we might draw the conclusion that several nonstructural elements as: electro-mechanic equipments, pipes for thermic agents, for water, gas, domestic hot water represent an individual system, with a certain utility, for example, producing thermic agent for heating and domestic hot water (*e.g.* thermic point) which at its turn represents a complex critical system whose behavior is important in case of a seismic event.

Equally, an oil station: it is made of both structural elements – tanks, and nonstructural elements – pipes for various fuels, creating on the whole a critical system.

Within the urban fund, an important number of critical systems can be identified, that is those systems whose malfunction in some case of an earthquake can lead to other disasters affecting the man and/or the environment.

For many existing critical systems, the danger emerges from the structures, fact that there are not designed and built in compliance with the seismic design criteria of the equipment. Even some of the current design and rehabilitation codes contain inadequate provisions for equipment protection in case of an earthquake. Thus, it is possible that certain structures from certain critical systems to resist severe earthquakes without serious damages, while other existing equipments, which represent "the content" of the structures, may be damaged or entirely destroyed (*e.g.* pressure tanks: boilers, expansion vessels; mechanic equipment existing in a thermic point).

That is why we consider to be relevant that those critical systems, whose state of function must be viable both during and after the earthquake and *operability* be preserved, be located within an urban fund or even in a certain area of that urban fund which is more vulnerable to a seism from the point of view of the existing buildings (antiquity, degradation stage, etc.).

From the past experience and studies of the effects of various earthquakes upon some cities, we reach the conclusion that not benefiting from the operability of the system, its malfunction occurs due to four types of seismic interaction [1]:

a) proximity, wich means potential impacts of adjacent equipment or structures due to their relative motion during an earthquake;

b) structural failure and falling of overhead or adjacent structures, systems, or equipment components;

c) flexibility of attached pipelines and cable;

d) flooding due to the earthquake induced failures of tanks, vessels or pipes.

2. Nonstructural Elements of Critical Urban Systems

2.1. Generalities

Nonstructural elements contained within an urban area are very different consisting of various equipments, unit networks, technologic networks with different destinations [2].

Nonstructural elements differ a lot as far as certain characteristic are concerned, such as:

a) the nature and quantity of deposited substances and the associated danger;

b) operation demands during and after the seismic event;

c) environment conditions.

Subsequently two limit conditions or states can be defined:

a) *Limit State Performance* necessary to obey one of the conditions of this state: total integrity or maximum operating level depending on the characteristics and the purpose of the considered elements.

The "total integrity" condition implies the fact that the considered system (*e.g.* a thermic system plant, referring strictly to the part of equipment and existing piping, and not to the building *per se*) remains durable and resistant along a seismic event of an annual probability of outrunning the prescribed values. The actual values shall be established on the basis of loss consequences of system operability.

Demands regarding the "minimum operating level" imply that the considered system may undergo a certain amount of damage to some components amount that will be estimated after loss control. The capacity of the system may be introduced up to the predefined operating level. The seismic event for this limit must to have a value based on the losses connected with the reduced capacity of the system and the final repairs.

b) *Final limit state.* According to [2], the final limit state is defined as the one corresponding to the loss of the operational system capacity, with the possibility of partial recuperation and conditioned by a sum of acceptable repairs.

Certainly, there is the possibility that certain damage of particular elements of the system imply maximum risks, just as, there also is the possibility that deterioration of the mentioned elements does not imply important risks. In the first case, the final limit state will be rendered by that of breakdown, while in the second case, it will lead to total collapse.

The referential seismic event, for which the final limit state must not be outrun, will be established according to the direct and indirect losses produced by the damaging of the considered system.

2.2. Piping Systems

The study case of piping systems may be used as basic for evaluating the resistance or the increase of the necessary redundancy for the existing utility networks, as has been presented in [2].

A piping system covers a wide geographic area subdued to different seismic hazards and different soil conditions. Moreover, a large number of sub-systems can be located along the piping system, associated with installations as: tanks, tub hearths, pump hearths, electro-mechanic equipments. It is very important to take into consideration the behavior of these critical components in case of a major earthquake so that their malfunctioning during or after the event does not produce important damages.

Considering all these aspects, for a differentiation of the demands for rehabilitation, the classification of the piping system is compulsory as follows:

a) *1st class.* System whose performance are vital; his functioning must be continuous. These are essential for the safety of the functioning of certain critical subsystems in case of a seism, in order to prevent major human losses, and not to have a destructive impact on the environment (*e.g.* fire extinction equipments).

b) *2nd class.* Respectively systems that must remain operational after the earthquake, but their functioning is not necessary during the event. The installations are vital, but interrupting their operating is possible for minor repairs, which is not accepted for the components of the installations that might cause great life losses.

c) *3rd class.* Systems containing the equipment systems whose malfunction may be acceptable even for a longer period of time until the execution of the repairs, this aspect not implying major damage or human life losses.

For all these classes a factor of importance, γ_1, corresponding to the most common installation systems, is defined according to Table 1, following recomandations from [2].

Table 1

Use of the structure/facility	Class		
	1	2	3
Potable water supply, non-toxic, non-inflammable material	1.2	1.0	0.8
Fire fighting water, non-volatile toxic material, low flammability petrochemicals	1.4	1.2	1.0
Volatile toxic chemicals, explosive and other high flammability liquids	1.6	1.4	1.2

Following requirement causes are taken into account:

a) *Serviceability requirements.* In the piping systems *limit state performance* have to remain operational even under a high degree seism which induces considerable local damage.

For system in *Final Limit State*, the corresponding to the level of seismic protection begins with evaluating the hazard and the seismic risk. Explosion and fire are hazards directly associated to the break up of a pipe in the conditions of a seismic event. The distance of the location and the population apparently subject to the impact of such a break-up must be considered when establishing the protection level.

b) *Analysis methods in case of underground pipe networks.* Pipe networks are very vast and complex and must be considered on the whole, which is possible through the identification of the networks in a global one.

The identification can be realized starting from the separation of a larger part (*e.g.* separating an urban network) or by separating the networks according to the functions performed within the same system (*e.g.* within an existing water supply there is a larger number of different networks, due to the functions performed: fire extinction water network, consumption water network, irrigation network) [3].

This separation allows treating differently the two systems even if it is not physically achieved: two different networks with common elements.

In general, the underground pipe networks must be placed in verified soils and stable soil for the considered seismic action. At the same time, we must mention the possibility of occurring two extreme reactions after the seismic event: soil liquefaction and fault movement. This implies specific design solutions in each case, separately.

a) *Seismic action model*

The movement of the soil in case of a seismic event is made of a mixture of waves depending on the depth of the location of the focus and its situation from the studied location [2].

Besides the fact that the waves vary, they also have different conduction speeds. Geophysical studies may provide important information, but they are generally not suitable for building the real model, and that is the reason why there appeared a series of deterministic models regarding this issue:

i) modelling the wave – considering only one model of the wave, that is the most unfavourable one for a certain effect over the pipes; the tendencies of the wave may be easily built (modeled) based on the spectrum of response through the designation for each frequency component of an estimate value of conduction speed;

ii) static modelling – a number of numerical simulations indicate the fact that inertia forces resulting from the interaction soil – pipe are much more reduced in comparison with the forces induced by the soil distortion; this allows the reduction of the interaction problem soil – pipe to one static issue (*e.g.* the distortion of the pipe is the result of the passage of the displacement wave without taking into consideration the dynamic aspect of the problem).

b) *Methodology*

The methodology of resolving the impact of these wave models over the piping systems in case of a seismic event supposes the use of a simple method, of demonstrated accuracy representing the supposition that the pipe is flexible enough to follow without any slidings or interaction the distortion of the soil; thus, according to [2], the movement of the soil is represented by only one sinusoidal wave,

$$u(x,t) = d \sin \omega \left(t - \frac{x}{c}\right), \tag{1}$$

where: d is the total displacement amplitude and c – the apparent wave speed.

Within this metodology, the motion of particles is supposed as occurring along the conduction direction (compression waves) and perpendicularly on it (shearing waves). For simplicity, one can consider the most unfavourable situation when the pipe axis and the conduction direction coincide.

If the pipe axis and the conduction direction do not coincide, in both cases of waves some great longitudinal and curved efforts are produced due to the angle, ν, of two directions. In this case the longitudinal strains is

$$\varepsilon(\nu) = \frac{\nu}{c} f_1(\nu) + \frac{a}{c^2} f_2(\nu) R, \tag{2}$$

where R is the diameter of the pipe.

The second term of the relation is much smaller in comparison with the first so, the maximum of the sum is given by relationship

$$\varepsilon(\nu) = \frac{\nu}{c} \tag{3}$$

c) *Interpretation of results*

The interpretation of results is based on "time-history" analysis of the forces activating on the pipe in a certain period of time, considering the conduction of the wave along the system or perpendicular on it.

According to the intensity of the action forces on the pipes, in the system various displacements can occur, which eventually may lead to the damage of the system through breaking or critical situation.

3. Case Study

The utility networks that are present in an urban area, as we have already seen, are different both from point of view of geometrical characteristics and also from point of view of the circulated agent. In this way, a pipe system that transports cold water can be considered a critical system in case of major seismic event because system non-functionality during or after the earthquake can produce major damages.

By means of numerical model design, and with help of the programme SAP 2000 it was achieved the study of the ramification behavior (t-square), the isolated part of the cold water network of Jassy city, taking into account that the pipes system chosen here is frequently met in the structure of the utility network existent for a present urban setting.

3.1. System Geometry

The pipe section considered here is made of steel, ⌀319×8 mm, set in the gutter having as supporting elements (metallic brackets) at a distance of 6.8 m, with a ramification of 90° at the middle of the distance between brackets, ⌀108×4 mm. (Fig. 1).

The circulated agent is cold water, with a work pressure of $p = 2$ bar

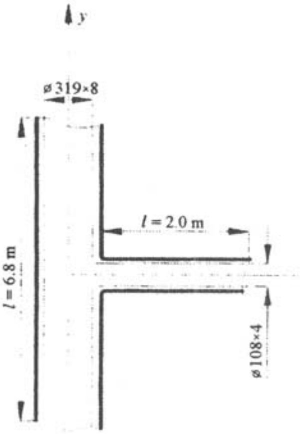

Fig. 1

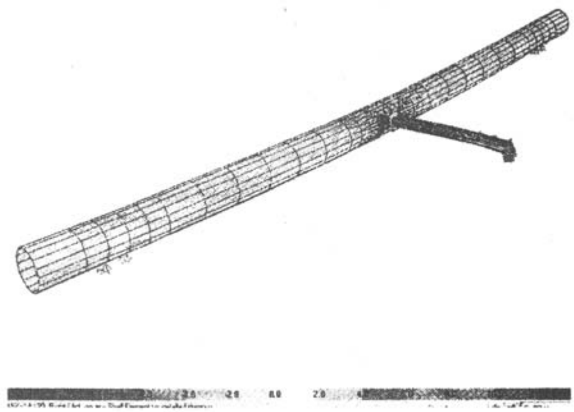

Fig. 2

3.2. Pipe System Modelling

The considered system being isolated in a cold water network of great extent, the pipe brackets were designed in a manner in which they could not produce any displacement alongside the main pipe axis, respectively along the ramification axis.

The design was made in the programme SAP 2000, the system being discretized in a number of 580 finite elements (Fig. 2).

3.3. Pipes System Behavior Analysis

There are taken into consideration two distinct situations:

a) The system is subject not only to the interior pressure action, $p_i = 2$ bar, owed to the circulated fluid - *static analysis* (Fig. 2).

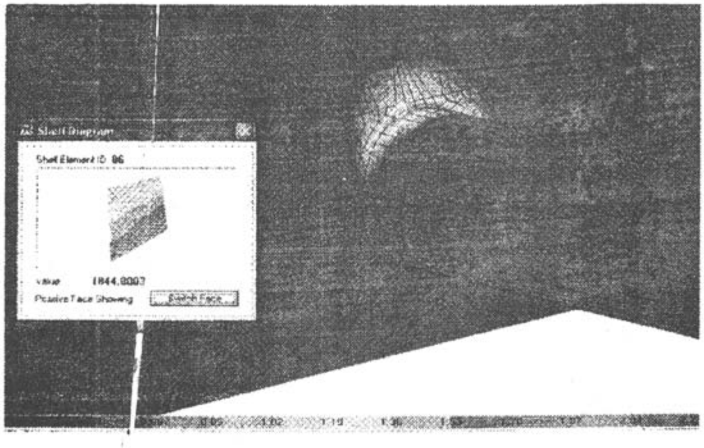

Fig. 3

b) The system is subjected both to the interior pressure action, and also to the action of the seismic event using the accelogram of the Vrancea earthquake from 1990; its PGA=980 mm/s^2 was registered by the INCERC devices – *dynamic analysis* (Fig. 3).

c) *Modal analysis* – modal periods and frequencies (Table 2).

Table 2

Output case text	Step type text	Step number	Period s	Frequency cyc/s	Circ. freq. rad/s	Eigenvalue rad^2/s^2
MODAL	Mode	1	0.026516	3.7713E+01	2.3696E+02	5.6150E+04
MODAL	Mode	2	0.017941	5.5739E+01	3.5022E+02	1.2265E+05
MODAL	Mode	3	0.010541	9.4872E+01	5.9610E+02	3.5533E+05
MODAL	Mode	4	0.009274	1.0783E+02	6.7751E+02	4.5902E+05
MODAL	Mode	5	0.008695	1.1501E+02	7.2262E+02	5.2217E+05
MODAL	Mode	6	0.005718	1.7487E+02	1.0988E+03	1.2073E+06

d) Results (Table 3).

Table 3

Analysis type	Stresses, [N/mm^2]		Displacements, δ, [mm]			
	Minimum	Maximum	Minimum	Maximum		
Results				x	y	z
Static	16	16.8	–	–	–	0.3
Dynamic	2,240	2,520	–	7	0.2	4

4. Conclusions

It is well known that in a certain urban area there are numerous systems considered critical due to the importance of their behavior in case of a seism and post seism. That is why the development of the informational infrastructure is compulsory in order to offer precisely data about these systems.

The informational infrastructure can be conceived as a digital map for a certain area, maps containing all existing critical systems, according to the classification made in this paper.

The monitoring of the seismic behavior of the critical systems existing in agglomerated urban areas can be performed based on this informational infrastructure. Thus, through the analysis methods presented for the underground piping networks important results may be achieved, as far the seismic vulnerability of the various existing utility networks in the urban fund.

We notice that an earthquake with the presented characteristics has a destroying effect over the pipe systems resembling the one subject to the analysis. The obtained maximum tensions are much over the accepted resistance of steel and are met in the joining spot; the system collapses first in this area.

Based on a time-history analysis of the forces acting on the pipe in a period of time, taking into account the propagation of the seismic wave, for the main pipe, being perpendicular on its axis, resulting a ramification along the axis, and function of the intensity of these forces, there were obtained maximum values for displacements, δ_{max}, that can lead also to system damage.

A general criterion for minimizing a displacement is that of introducing maximum flexibility into the system subdued to movement. This can be achieved by: a) decreasing the underground depth in order to reduce the compulsion of the soil; b) executing large ditches for pipes that need to be filled with soft material.

Received, November 13, 2006

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STADIUL TEHNIC ACTUAL AL SISTEMELOR CRITICE EXISTENTE ÎNTR-O ARIE URBANĂ SEISMICĂ

(Rezumat)

Lucrarea este structurată în trei părţi principale. În prima parte se face o clasificare a sistemelor critice existente în fondul urban, ce intră în componenţa unei infrastructuri informaţionale de necesitate majoră în cazul unui eveniment seismic. Sistemele critice sunt identificate ca fiind acele sisteme a căror nefuncţionare poate conduce la dezastre ce afectează omul şi/sau mediul înconjurător.

În cea de a doua parte se insistă asupra reţelelor de conducte îngropate, prezentându-se, de asemenea, o clasificare a acestora pe trei clase de importanţă în cazul unui seism, urmând, în ultima parte a lucrării, prezentarea unei metodologii de analiză şi a unui studiu de caz pentru analiza comportării seismice a reţelelor de conducte, considerate ca făcând parte din sistemele critice existente, în cazul unui eveniment seismic, într-o zonă urbană.