FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 9, No 2, 2011, pp. 231 - 240
DOI: 10.2298/FUACE1102231Z

SEISMIC HAZARD IN THE DESIGN OF OIL AND GAS PIPELINES*

UDC 550.34:532.542:622.323:622.324=111

Slavko Zdravković, Biljana Mladenović, Dragan Zlatkov

University of Niš, The Faculty of Civil Engineering and Architecture, Serbia

Abstract. *Criteria that are adopted in earthquake resistant design of pipelines and gas lines have to take into account seismic movements and seismic generated forces that are of significantly high probability level of appearance along the length of pipeline. A choice of criteria has to include an acceptable level of seismic hazard, while design criteria should be calculated. Seismic hazard is defined as a part of natural hazard and means probability of appearance of earthquake of corresponding characteristics in certain time and place. For design needs and calculation of influences caused by seismic forces the most important is seismic hazard of maximal horizontal acceleration due to ground vibration during earthquake. The methodology of seismic hazard calculation as base for micro seismic zoning is presented in the paper. It is shown calculation of seismic hazard of maximal horizontal acceleration due to ground vibration that is applied for 985 points at the territory of Republic of Serbia, based on which maps for return periods of 50 and 200 years are drawn..*

Key words: *hazard, oil pipeline, gas line, fire, earthquake resistant design.*

1. INTRODUCTION

Complex earthquake mechanism nature and heterogeneous surface ground layers are the main reasons for very hard determination of local ground movements during strong earthquakes, although internal forces in some structure during earthquake depend not only on ground movements but also on mechanical properties of the structure itself. As essential characteristics of some future earthquake could not be determined reliably, the seismic loading cannot be determined strictly too. Available methods of assessment of seismic risk and hazard of defining parameters of seismic action for structural design are

Received September 25, 2011
* **Acknowledgement**. This research is supported by the Ministry of Science and Technological Development of the Republic of Serbia, within the framework of the Technological Development project No TR36016 for project cycle 2011.-2014. "Experimental and theoretical investigation of frames and plates with semi-rigid connections from the view of the second order theory and stability analysis" of the research organization The faculty of civil engineering and architecture of University of Nis.

based on experience from past earthquakes damages, laboratory and terrain research of specific materials, soil and structures. Such data give possibility to define economically justified design and construction criteria with needed level of engineering assessment of accuracy. Structural solution which is optimal when earthquake influence isn't taken into account doesn't have to be even acceptable in earthquake resistant design.

Very often in everyday engineering praxis, sometimes even in professional literature, terms seismic risk and seismic hazard are identified although they have quite different meanings in defining earthquake effect as natural phenomenon. Precise meanings of these terms were defined by experts in this field on The Conference of UNDRO (Disaster Rescue Organisation) in Geneva in 1979. In accordance with this, seismic risk is defined as expected level of losses caused by effects of future earthquakes (destroying and damaging structures, wounded and dead), direct and indirect economic, functional, social and other losses. Seismic hazard is defined as a part of natural hazard and means probability of occurrence of earthquake of corresponding characteristics (magnitude, velocity, ground acceleration) in certain time and place. Results for seismic hazard and risk are different in qualitative sense. Seismic hazard defines probability of earthquake occurrence, i.e. means prognosis of the level of future earthquakes and due to possibility of direct application it contributes to decreasing of seismic risk. Solution of the problem, that means making a decision about the level of acceptable seismic risk and choice of optimal construction, can be formulated by combining the parameters of seismic hazard with parameters of the construction defined through earthquake resistant design and regulations for designing and constructing in seismic areas.

So, earthquake resistant civil engineering represents series of contradictories and opposites for which it is necessary to find out an optimal compromise, but what is important is that compromise is not at the account of security and safety of people. This is the reason why there are three directions in the contemporary approach of fight against this natural disaster: research of the nature of this phenomenon ("hearth seismology"), study of interaction between geological medium, earthquake and the construction ("surface seismology"), as well as investigation of civil engineering structures in dynamic action conditions (earthquake engineering). Investigation of this very complex phenomenon requires multidisciplinary and interdisciplinary approach.

2. Criteria of Earthquake Resistant Design

Criteria that are adopted in earthquake resistant design of an oil pipeline and a gas line have to take into account seismic movements and seismic generated forces that are characterized by a great probability of appearance along the trace of a pipeline. A choice of criteria has to include an acceptable level of risk and hazard, while design criteria would be calculated.

Design criteria are to be based on two different seismic risks, according to procedures that are adopted for nuclear power stations. Designing of pipelines with lower and more probable seismic risk, that can be designated as "probable design earthquake" (PDE), it is necessary to take 50 years as return period, while maximal risk or "maximum design earthquake" (MDE) have to be considered for return period from 100 to 200 years (according to Prof. W.D.Lian Finn, Canada) [1]. It would be ideally if pipeline could continually be on service during PDE and after it, and if MDE would not cause unexpected damages. If data about seismicity of a zone are not exactly defined, these two risks are expressed depending one on the other, i.e. ratio between MDE and PDE has to be taken as 2.

There are two types of pipelines: in-ground and above-ground supported on bearings. In the first case a pipe usually follows deformations of the soil, while in the second case reaction will be determined from structural characteristics of the pipeline system. Because of that different design criteria have to be used for in-ground and above-ground pipelines.

3. Seismicity and Seismic Movements

The most number of pipelines probably will pass through the regions with different (changeable) seismicity because of their length. So, the first step is to divide the pipeline trace into sections with defined constant seismicity. Earthquakes with magnitude of 7 degrees, or stronger, are possible only on, or near, certain existing faults, in which movements have been manifesting in last 50000 or 100000 years. Earthquake with magnitude less than 7 degrees can occur in regions where faulting has not been manifested or has not appeared at the ground surface jet.

There are two types of interaction between pipeline and soil.

- In-ground pipelines are considered to undergo the same movements as surrounding soil, namely equal curve and equal longitudinal deformations. In order this condition to be valid, the soil that surrounds the pipeline has to remain unchanged (for example, if soil stiffness is too much changed, because of liquefaction, these deformations have to be taken into account later).
- In the case of above-ground pipelines, ground movements are transmitted to the pipe by columns or bearings. Deformations of such bearings have to be taken into account, as well as twisting of bearings under their foundations.

Both in the case of in-ground and above-ground pipelines we have to allow for possible relative movements in faults that are crossing the pipelines. Both horizontal and vertical displacements larger than 1.0 m can occur as result of movements along a fault. Correctly designed above-ground pipeline probably could undergo relative movements of 1.5m without destroying, although one or two supports will lose contact with a pipe. In the case of in-ground pipelines such great movements can cause large local dislocations, but if a pipeline is adequately designed it would not be destroyed.

The most dangerous movements occur in rock faults, because relative movements appear in considerably small distinct. In such cases corresponding measurements have to be taken in order to protect a pipeline from such sudden displacement changes. The protection could be provided if a trench is dug, in vicinity of a fault, with rather equal slopes, and a pipe covered with limited depth of gravel (less than 2 m), so that the upper surface is rather plane and a pipe could move up and aside but should not crack. Anchors should not be applied if a curve is less than 100 m fare from a fault and if it is under right angle.

In what follows, parameters to which attention has to be paid when a trace of a pipeline is designed are cited:

- level of allowed seismic response;
- design spectra;
- combined seismic movements;
- gravitation load;
- twisting.

Above-ground pipelines should be specially treated in earthquake resistant design. Concentration of stresses in connections and supporting joints should be taken into account. The procedure for in-ground pipelines has to include the analysis of longitudinal deformations.

The draft of regulation about technical normative for design and calculation of engineering structures in seismic regions [11] provides calculation of seismic pressure in the case of underground and in-ground (shallow or deep) constructions.

For constructing the pipeline under pressure deformable connection between pipes has to be provided in order to enable translator displacement, especially at the entrance and exit of a building or a tank, at the connecting points with pump, at the connecting points of vertical and horizontal pipes, at all places where direction is changed a lot, and at places where pipe profiles change rashly. Steel pipes can be connected by welding, with requirement they to be particularly strengthened. Welding of steel pipes to the pieces made of cast iron or some other brittle material is not allowed.

4. Basic Principles of Seismic Hazard Design

Occurrence of earthquake is one stochastic process from the statistical point of view that is mathematical model of considered physical system which changes in accordance with probability rules (Lomuitz, 1976). Poisson's statistical process represents a stochastic process, which expresses the position of individual accidental event (in our case an earthquake) in time. Based on results of the observation of real seismic activity, Poisson's model enables statistical prediction of future seismic activity characteristics relevant for definition of seismic hazard at the considered area.

As the basic source of data about earlier earthquakes on the territory of Serbia and surrounding areas catalogue of quakes is used in which chronologically are systematized all data from 1900 to 1970, (Catalogue is made for needs of regional Balkan-project). Beside these the data about earthquakes for the period 1970-1985 was used. (Catalogue of Seismology institute of Serbia) so that the whole observation period is 85 years.

Besides the map of epicenters of earlier earthquakes, for the purpose of designing of focus regions, data about tectonic, neotectonic and seismotectinic characteristics of the region. For each focus area possible magnitude values for return period from 50 to 200 years are determined. 44 focus zones that have or can have an influence on seismicity in Serbia are designated at neighbour territories. The influences of far focuses are observed too, such as: Kečkemet, Vrančea, Rila, Berovo, Valandovo, Južni Jadran, Dubrovnik.

From the definition of seismic hazard, it is clear that the deterministic methods cannot be applied, but methods of mathematical statistic and probability theory. It outcomes also that seismic hazard is defined by three mutually depending elements such as: magnitude of ground vibration parameters, return period and probability of realization of such event. These necessary elements for defining of seismic hazard can be analysed separately or explicitly expressed as their mutual dependence (Fig. 1).

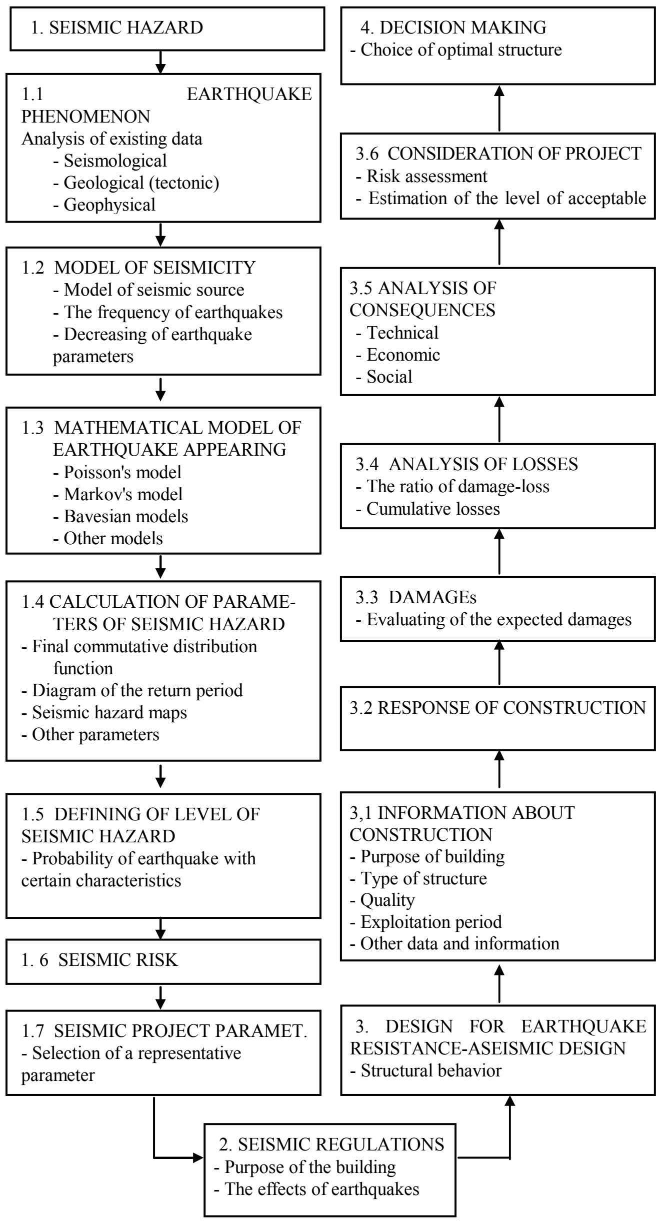

Fig. 1. Dependence of parameters of potential focus

The most often, regarding further direct application, maximal seismic parameter in the frame of certain return period with defined probability is expressed.

In the theory of probability different distributions are used, among which is already mentioned Poisson's distribution, which is particularly used in seismic hazard design.

The following expression is used for Poisson's distribution:

$$P = \frac{m^x e^{-m}}{x!} \tag{1}$$

The same formula is used in determining probability of occurrence (n) of earthquake, with defined magnitude (M) in time (t) that can be written in the form:

$$P_{(n,t,\lambda)} = \frac{[\lambda(n)t]^n e^{-\lambda(M)t}}{n!} \tag{2}$$

where it is:

P(n,t,λ) - probability of occurrence *n* quakes of magnitude greater or equal M;

n - number of earthquakes;

m - number of repeatable cases;

λ - mid value of number of earthquakes with defined magnitude in time unit (one year). In that way λ is equal N.

As the relation between frequency of occurrence, that is number of earthquakes (N), and magnitude (M) is given by expression:

$$\log N = a - bM \tag{3}$$

$N=10^{(a-bM)}$, N= λ, one obtains:

$$P_{(n,t,\lambda)} = \frac{[10^{(a-bM)}t]^n e^{-10(a-bM)}}{n!} \tag{4}$$

where is:

N – number of quakes with defined magnitude M for determined number of years;

a,b – constants of relation which characterized the focus area.

For the purpose of occurrence probability of an earthquake the most important is to determine ratio between magnitude and occurrence frequency of that earthquake.

Poisson's model, as it has been already said, is the most often used for seismic hazard calculation that is determining of the probability of acceleration occurrence. In that case instead of magnitude (M), the acceleration exited by this magnitude is taken, while ratio between them is determinate by use of the attenuation function:

$$F_{(n,a,t)} = \frac{\lambda(a)t^n e^{-\lambda(a)t}}{n!} \tag{5}$$

So, the probability of occurrence *n* accelerations in time *t,* with intensity higher or equal to *a,* is obtained by use of the expression (5).

5. Values and Maps of Seismic Hazard for Maximal Horizontal Ground Acceleration

With the task to choose optimal method for calculation of seismic hazard of maximal horizontal ground acceleration on the territory of Serbia necessary analysis of the published methods, which treat this problem, has been carried out. The method of Angermisen is adopted as method for seismic hazard calculation, which includes application of Poisson's model for generation of quake (UNESKO, 1975).

Seismic hazard of maximal horizontal ground acceleration is calculated in ten steps in the following way:

1. All relevant seismic zones are divided by the elements and the segments and a function of repeatability of earthquake is assigned to each element.
2. Distance of each element from the point, where seismic hazard is to be determined, is calculated.
3. The number of earthquakes that will be generated in some elements of seismic zone is calculated by use of repeatability function with a step ΔM (ΔM is adopted as 0,2).
4. Inducted effect of ground acceleration is calculated using equation of attenuation ($M_i = M_{i-1} + \Delta M$).
5. Successively after each step a partial sum of induced effects is formed based on their number and intensity of these effects.
6. The procedure is repeated for each element of seismic zone, so that cumulative distribution is supplemented step by step.
7. Identical procedure is applied for all other seismic zones.
8. The final cumulative distribution for the location is formed, as well as the sum of all partial sums.
9. Inversion of the final cumulative distribution as function of return period is done by use of Poisson's model.
10. The procedure is continued for all points of the mesh.

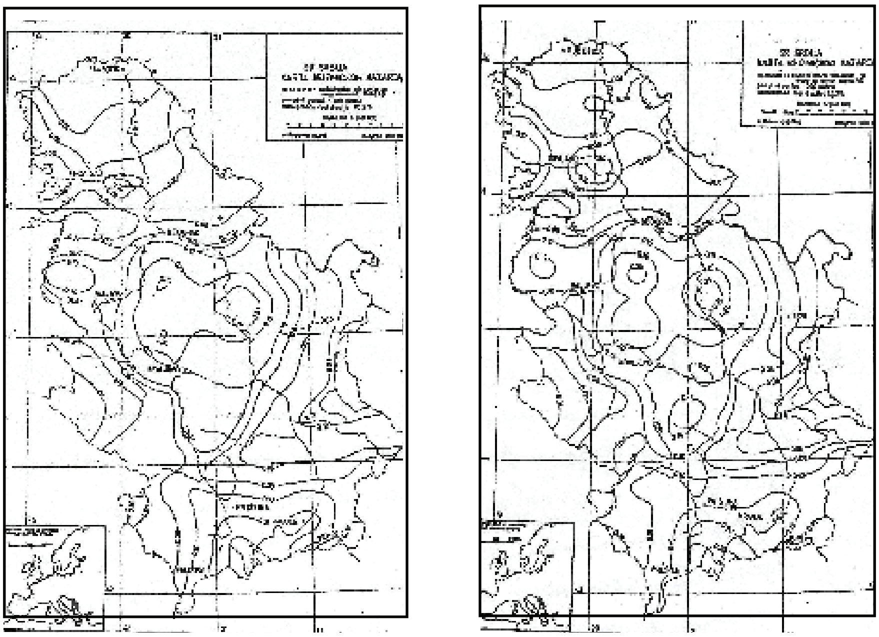

Fig. 2. Seismic hazard maps of the Republic of Serbia:
for return period of 50 years (left) and for return period of 200 years (right)

Seismic hazard of maximal horizontal ground acceleration is calculated for return period of 50 and 200 years carrying out above described procedure with probability of realization of 0,632, i.e. the most "probable probability". The calculation has been done for the mesh of uniformly arranged points at the whole Serbian territory. The points are located at mutual distance of 0,1 degree of latitude and 0,15 degree of longitude, so that the entire territory is covered by 985 points. The maps of seismic hazard of maximal horizontal ground acceleration (vertical accelerations are 0,6 to 0,7 of horizontal ones) for return period of 50 and 200 years are drawn based on numerical results obtained by use of above described procedure (Fig.2 from [6]). Isolines of seismic hazard define very well locations of the main seismic areas on the territory of Serbia. Clearly are separated locations of Fruška gora, Krupanj, Lazarevac, Rudnik, Svilajinac, Kopaonik, Vitina and Vranje. Influences of these heart zones are such that cause induced effects in other regions and in some way they determine seismicity of the whole territory of Serbia.

6. Examples of Protection of Gas Lines and Gas Storage Tanks Against Earthquake

The first example is from Macedonia, where a mechanical seismic stop valve for gas blockade has been constructed.

Seismic instruments that have a role of detectors of seismic events are seismic starters and seismic stop valves. Seismic stop valves react on stronger earthquake excitations and have the task to activate certain protection devices to stop process and to alarm.

Mechanical seismic stop valve can be applied in urban environment for gas blockade in etagere installation. The second possibility for use is in protection of highway gas lines, industrial installation (for example electric systems, heating plant, factories whose raw material is natural gas) and so on.

Mechanical seismic stop valve was tested in June 1995. in the Institute for Earthquake Engineering and Engineering Seismology of the University "Sveti Kliment" in Skopje (Macedonia).

The whole investigation has been organized and carried out by specialists from The Institute and Petrochemistry and have been presented in the elaborate: "Experimental investigation of dynamic characteristics and functionality of a prototype of stopping gas valve in gas line substations during earthquake effect".

Functional investigation of the device has been done in the conditions of real earthquake and sensitivity threshold has been determined. The investigation has shown that the device has maintained its function and repeatability, so it is applicable for its purpose.

Mechanical seismic stop valve is created with basic aim to protect human lives and material goods by automatic stopping of gas flow in gas installation when earthquake begins. Comparing with up-to-now known similar devices, it has a lot of advantages because of its original construction [3].

The second example is from Japan, as this country is in seismically active zone prone to severe earthquakes. The Hanshin Earthquake in January 1995 had the magnitude of 7.2 on the Richter scale, with its epicenter near the city of Kobe. More than six thousand people died during this earthquake and many structures were severely damaged. While no liquefied natural gas storage tanks were in the immediate vicinity of the epicenter, within the radius of 35 km there were more than thirty such tanks and among them one prestressed concrete storage tank described in [4]. Although these tanks were subjected to horizontal ground acceleration of 1.9-2.4 m/s, they suffered no damage.

There were also three conventional double-walled liquid propane gas storage tanks near the hard-heat area. One of these tanks experienced a leak at the flange joint of a stop valve on a combined inlet/outlet line. The main cause of the leakage was settlement and the lateral movement of the support frame foundation due to ground liquefaction. There were no damages of the tank itself, and this fact validates the design. However studies are currently reappraising seismic design codes for storage tanks in Japan to provide even greater safety and reliability in response to earthquake.

7. FIRES AS COMPANIONS OF EARTHQUAKES

Fires that break out as consequence of earthquake can be classified in two main groups:

- primary- caused by destroying of walls, structures, pipelines, electrical systems during earthquake or caused by fire from furnace, range or lamp;
- secondary – appear when a fire from neighbor burning building is transmitted to the others.

Damages and collapse of installations, large factory sections, storehouses of inflammable materials and liquids also can cause fire immediately after earthquake stroke.

Great fire that appears in a severe earthquake very often causes greater damages than tremendous power of an earthquake. Some characteristic examples will be cited as illustration.

During Lisbon earthquake, Portugal, in November 1755, in which more than 75% of all buildings in the town were damaged, great fires broke out and finished off catastrophe caused by seismic shakes.

The California earthquake, USA, in April 1916, when particularly the city of San Francisco suffered great damages, caused many fires in this city. The fire mainly spread over north-west part of the city. The city Santa Rose was destroyed too, and underwent many great fires as consequence of the earthquake.

During Meson earthquake, Italy, in December 1908 a great fire broke out and lasted three days and nights. Strong wind contributed the fire to be transmitted to surrounding undamaged buildings as well as to the ships in the port and anchorage.

Disastrous earthquake that strike Japan in 1923, 1st of September, also caused great fires in many towns. However, Tokyo and Yokohama suffered the most, knowing that 447128 building burned to the ground. Damages caused by fire were much greater than those caused by the earthquake. Many fires broke out because of transmission from one primary inflamed building to the others in vicinity, so that primarily fires appeared in only 67 places. Fires in Tokyo have lasted for two days. About a million inhabitants of Tokyo remained without roof and about 50000 people burned in fire. In Yokohama two thirds of all buildings burned to the ground, while 23 of 60 primary fires broke out in residual buildings. As the city was thickly erected, the fire spread easily from one building to the other and many secondary fires broke out in that way.

Having in mind nowadays technical and technological development of the human society, danger from fire during earthquake increases a great deal since the concentration of inflamed materials is high.

Since it is very difficult to prescribe the possibility of fire appearance depending on structure type, it has to be paid corresponding attention to each type regarding the fire resistance.

8. CONCLUSION

Earthquake is a natural disaster which causes varied damages to up-to-date civilization: destroys urban environment, kills people, damages material goods in settlements, damages or destroys communications, industrial plants. The secondary catastrophes occur as effect of earthquake, such as fires, collapse of communal systems (power stations, water supply, gas lines, oil pipelines) and so on.

Researches in earthquake engineering and engineering seismology generally are aimed towards construction of earthquake resistant structures. The modern seismic design has improved seismic resistance of structures but more work is needed to mitigate the effects of earthquakes on communities.

Having in mind up-to now catastrophic consequences caused by earthquakes, for example uncontrolled run-out of gas from gas lines in Los Angeles 1994 and Kobe 1995, that caused disaster fires, human suffering and material damages, application of mechanical seismic stop valve could be very efficient for avoiding such experience. Mechanical seismic stop valve has also ecological characteristics.

REFERENCES

1. Finn Liam W. D.: Dynamics of soil and special chapters on aseismic design of engineering structures, IZIIS, Skopje 1976.
2. Grujić N.: Seismic risk, Conference – planning, designing and construction of structures in seismic regions, Cavtat 1977.
3. Tresač S., Perišić B..: Protection of material goods and human lives-imperative of appliance of mechanical seismic stop valve for blockade of gas flow , Preventivni inženjering, 1993.
4. Sakai F., Mentani Y.: Prestressed LNG Storage Tanks in Japan, Structural Engineering International, 1997.
5. S. Zdravković, T. Igić, V. Savić, B. Kostadinov: "Eartquake resistant design of oil pipelines and gas lines", III International Conference – Risk in tehnological and the environment – RISK 97, Niš, October 1997, pp 111-114.
6. M. Petrović, Seizmički hazard kao jedan od elemenata seizmičkog rizika sa proračunom za teritoriju SR Srbije, Izgradnja 8/87, Beograd, 1987.
7. UNESKO survey of the seismicity of the Balkan region, Seismic risk evoulation of the Balkan region, U.S. Skoplje, 1974.
8. UNESKO survey of the seismicity of the Balkan region, Catalogue of earthquakes, III atlas of isoseisma 1maps, Skoplje 1974.
9. S. Vukadinović, Elementi teorije verovatnoće I matematičke statistike, Privredni pregled, Beograd,1976.
10. S. Ivanović, Inženjerska seizmologija, Građevinski fakultet Titograd, 1976.
11. Nacrt Pravilnika o tehničkim normativima za projektovanje I proračun inženjerskih objekata u seizmičkim područjima, Savezni zavod za standardizaciju, br.07-93/96, Beograd, 1997.

SEIZMIČKI HAZARD PRI PROJEKTOVANJU NAFTOVODA I GASOVODA

Slavko Zdravković, Biljana Mladenović, Dragan Zlatkov

Kriterijumi koji su usvojeni u aseizmičkom projektovanju naftovoda i gasovoda treba da uzimaju u obzir seizmičko kretanje i seizmičke generisane sile koje imaju značajno veliki stepen verovatnoće pojavljivanja duž trase cevovoda. Izbor kriterijuma mora da sadrži jedan prihvatljivi nivo seizmičkog hazarda, dok će projektmi kriterijumi biti proračunati. Seizmički hazard se definiše kao deo prirodnog hazarda i predstavlja verovatnoću pojavljivanja zemljotresa odgovarajućih karakteristika u određenom periodu i na određenom mestu. Za potrebe projektovanja i proračuna uticaja seizmičkih sila najvažniji je seizmički hazard maksimalnog horizontalnog ubrzanja pri oscilovanju tla za vreme potresa. U radu se prikazuje metodologija proračuna seizmičkog hazarda kao osnove za mikroseizmičko zoniranje. Prikazan je proračun seizmičkog hazarda maksimalnog horizontalnog ubrzanja pri oscilovanju tla koji je primenjen za 985 tačaka na teritoriji Republike Srbije, a na osnovu čega su konstruisane karte za dva povratna perioda - 50 i 200 godina.

Ključne reči: *hazard, naftovod, gasovod, požar, seizmički proračun*.