ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ СОФИЯ

Том Volume 51 | 2018 | Брой Issue 6

ANNUAL OF THE UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY SOFIA

Получена: 04.12.2017 г.
Приета: 16.12.2017 г.

SEISMIC RISK ASSESSMENT OF ELEMENTS OF THE TECHNICAL INFRASTRUCTURE – WASTEWATER

A. Kaneva[1], A. Vatralova[2]

Keywords: *seismic risk assessment, technical infrastructure, wastewater systems*

ABSTRACT

Based on review of some methodologies for seismic risk evaluation in Europe and the USA certain models for assessment of damages in wastewater systems in Bulgaria are chosen. Relevant classifications of the system components are analyzed in view of available data in the country. The application of the chosen models is illustrated and results are discussed.

1. Introduction

The seismic risk assessment is based on three main factors: the elements of the urbanized environment (inventory classification), the seismic hazard and the vulnerability expressed by a fragility curve, which is a function that gives the relation between the expected damage and the seismic hazard in terms of a suitable parameter of the ground motion. In the paper the focus of the discussion is wastewater infrastructure systems. Each infrastructure is built as a network of lines and nodes (pipes, buildings and facilities), which makes it quite different from the building stock. For example, the wastewater system infrastructure, which is of major importance in the normal period of a city (no earthquake), during and after a strong earthquake, consists of a network of sewerage pipelines and nodes that perform a specialized function: sewage pumping stations, wastewater treatment plants and other facilities.

Each infrastructure is a complex organism where, in case of a node or line failure, the entire system or parts of it are affected. Failures and disruptions in an infrastructure system can

[1] Antoaneta Kaneva, Assoc. Prof. Dr., Dept. “Engineering”, NIGGG-BAS,
e-mail: akaneva@geophys.bas.bg; kaneva_ant@abv.bg;
[2] Albena Vatralova, Chief Assist. Prof. Dr., Water Management Unit, NIMH-BAS,
e-mail: albenav@bas.bg; albenav@ mail.bg

affect other systems and disturb the normal operation in wider areas. The risk assessment of infrastructure systems is complicated because of the complexity and diversity of the conditions and the characteristics of the individual lifelines, facilities, and buildings. Usually seismic risk study is done on an individual infrastructure system in a restricted region and only direct losses are estimated. The SYNER-G project [1] makes a big step beyond that as the interaction between the different systems is considered and the functionality of the system after an earthquake is assessed. The HAZUS methodology [2] also treats some links between different modules and offers systemic analysis in a simplified manner.

In Bulgaria there are no observations of damages from past eathquakes to elements of the water supply and sewerage system infrastructure. The methodologies [1 – 3] can be applied for assessment of the impact of an earthquake to the wastewater system in the country. The classification of the elements of the wastewater system, the fragility functions and an example for application of chosen models of these methodologies to elements of the wastewater treatment plant and pipelines in Sofia are presented in the paper.

2. Classification of a Wastewater Infrastructure System and Damage States

Both methodologies [1, 2] classify the wastewater treatment plants (WWTP) according to the capacity of the plant as small, medium and large. The second factor that defines the vulnerability of the WWTP is the design of its components. The methodologies distinguish between two designs: sub-components designed for seismic loading in addition to standard design and sub-components with standard design or shortly, anchored and unanchored components. The components of WWTP are electric power, electric equipment, chlorination equipment, sediment flocculation, chemical tanks and elevated pipe. In [1] the typology of the building of a typical Greek WWTP is considered with two levels of the seismic code. The buried pipelines are classified as brittle or ductile in [2] while in [3] the material, diameter, age and type of joints define the pipes.

The damage states of a WWTP in both methodologies are the same: slight/minor, moderate, extensive, complete – for the components, and breaks and leaks – for the pipes.

3. Fragility Functions for Wastewater System Elements

The fragility curves are functions of an appropriate parameter of the ground motion – PGA, PGV, PGD[1], spectral acceleration, spectral displacement, peak ground strain, macroseismic intensity (MSK). For each element of a system of the urbanized areas the parameters that best fit the observed/estimated damages are considered in the fragility functions. For pipelines the majority of the existing fragility relations for wave propagation use PGV as a direct measure of the longitudinal ground strains [4, 5]. The available fragility functions [1, 2, 3] for the pipes correlate to repair rate/km (RR/km) in terms of PGV or PGD. PGV is related with ground shaking caused by seismic wave propagation, and PGD is related to ground failure such as liquefaction, landslides, fault crossing. For canals, PGV and PGD are equally used. For all other elements (wastewater treatment plants, lift stations) PGA is used [1, 2]. For the elements of the wastewater system, excluding pipes and canals, the fragility functions define the probability of an element to be in or exceed a damage state given the PGA.

[1] PGA – peak ground acceleration, PGV – peak ground velocity, PGD – permanent ground displacement

The curves are defined by median value of PGA and lognormal standard deviation, β. In the Greek project SMR LIFE [6], the curves for the wastewater treatment plants are based on HAZUS empirical curves of sub-components (anchorage of sub-components without following specific guidelines) while for the buildings, the fragility curves of the Greek typology “low-rise RC buildings“, which is common in Europe as well, are used. In Table 1 the median and standard deviation values are listed for the wastewater treatment plants provided in HAZUS and SYNER-G (SRMLIFE) [1, 6].

Table 1. Parameters of fragility curves for wastewater treatment plans

Description element	Description sub-components	Damage state	PGA Median, g	β (log-normal deviation)
Medium wastewater treatment plant (50 – 200 mgd) HAZUS (FEMA 2004)	anchored	Minor Moderate Extensive Complete	0.33 0.49 0.70 1.23	0.40 0.40 0.45 0.55
	unanchored	Minor Moderate Extensive Complete	0.2 0.33 0.7 1.23	0.40 0.40 0.45 0.55
Wastewater treatment plants SYNER-G (SRM-LIFE, 2007)	anchored components (low-rise R/C building with low level seismic design)	Minor Moderate Extensive Complete	0.15 0.30 0.45 0.50	0.35 0.20 0.50 0.50
	anchored components (low-rise R/C building with high level seismic design)	Minor Moderate Extensive Complete	0.15 0.30 0.45 1.00	0.35 0.20 0.50 0.50

As already mentioned for the pipes the fragility curves are in terms of repairs per km of the pipe length. The HAZUS empirical relation for pipes for wave propagation is:

$$RR \approx= 0.0001*(PGV) ** (2.25). \qquad (1)$$

Where, *PGV* (cm/sec), *RR* repair rate (Repairs/km).

This relation is for brittle pipes (concrete, clay, cast iron, asbestos cement). For ductile pipes (steel, PVC) in the above relation a factor of 0.3 is applied.

The linear model of ALA [3] provides fragility curves for buried pipes based on damage observations from 12 earthquakes mainly from the USA and Japan at 81 points. The linear model (2) stands for the so called skeleton curve for wave propagation if data for the material, diameter and age of pipes is not available:

$$RR = a *PGV, \qquad (2)$$

Where, *RR* is the repair rate per 1000 ft length of the pipe,
a = constant equals to 0.00187; *PGV* (inch/sec).

A factor K1 is applied to relation (2) when data about material and diameter of the pipes is known. The methodology provides tabulated values of K1.

4. Available Public Data for the Wastewater System in the Country

The Ministry of Environment and Water of Bulgaria (MoEW) published data for the length and year of construction of the wastewater networks in the four river basins in the country [7]. The data shows that most of the buried wastewater pipelines (about 70%) are built before 1980. Another source of public data in the country is the National Statistical Institute (NSI). There we can find the following data for the material of the wastewater system pipes, Table 2 [8].

Table 2. Type of the wastewater system pipes at the end of 2010

(Percentage)

	Total	Wastewater Mains	Wastewater Net
Total	100.0	100.0	100.0
Concrete	91.8	88.8	92.3
PE	1.4	3.1	1.1
PVC	3.2	3.6	3.1
Glass fiber	0.2	0.3	0.2
Other	3.5	4.2	3.3

The data in Table 2 shows that the prevailing type of the buried wastewater pipelines is segmented pipelines made of concrete.

The available information in the data of NSI for the wastewater treatment plants concerns the capacity of the plants (design capacity in terms of BOD_5 tons O_2/day) [8].

5. Sofia Sewerage System

The length of the sewers and collectors serving Sofia city is about 1700 km. In the website of “Sofiyska voda” AD “2013 numbers and facts” lists 1660 km sewers and collectors. From the data discussed above more than 90% of the length of the lifelines are made of concrete. That classifies the buried pipes as brittle according to the HAZUS. The sewerage system is of combined type that takes the community effluents as well as the surface water from rainfalls and snowmelt. That is why the wastewater facilities are designed to take hydraulic load equal to twice the maximum hourly flow in dry weather. The wastewater flows by gravity through the sewerage system of Sofia to the Sofia Wastewater Treatment Plant (SWWTP) “Kubratovo”. The wastewater treatment process includes two main lines – for wastewater and sludge treatment respectively.

The SWWTP “Kubratovo” (Fig. 1) is located in the lowest northern part of Sofia – Kubratovo district, on a total area of 60 ha. It treats the domestic and industrial wastewater as well as storm water entering the sewerage network of the capital city of Bulgaria. It is one of the largest WWTPs in the Balkans with design capacity of 500000 m^3 of wastewater per day (at present the real effluent treated is about 400 000 m^3 per day). The facility was designed in the period 1973 – 1975. So far it has operated for more than 30 years without interruption, being subject to partial reconstructions and improvements.

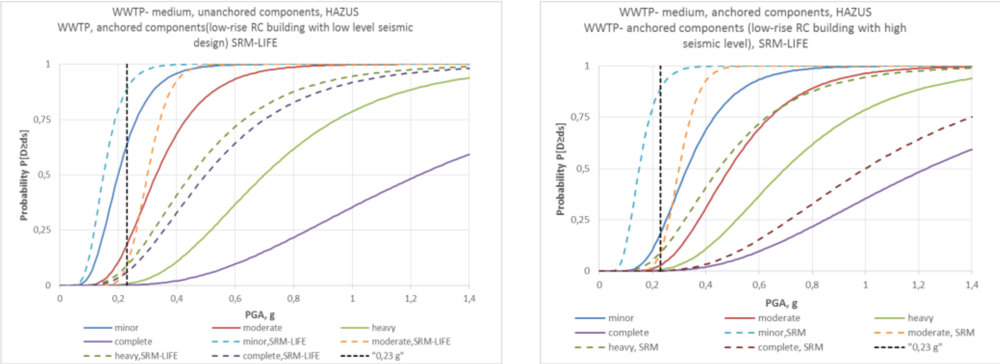
Figure1. The SWWTP "Kubratovo", Source: Sofiyska Voda AD

The design capacity of the Sofia WWTP classifies it as a Medium WWTP according to the HAZUS Earthquake Model [2].

6. Application of the Methodologies and Results

As an illustration the HAZUS and SMRLIFE/SYNER-G fragility functions were applied for the Sofia WWTP. The SRM LIFE project/SYNER-G classifies the WWT Plants as with anchored components but considers the level of seismic design of the building as high or low. The building is reinforced concrete (RC) low-rise. In Fig. 2 a) and b) the fragility curves of both methodologies for WWTP are presented. The solid lines are for the curves of HAZUS and the dashed lines are for the curves provided by SRMLIFE. According to the seismic hazard map for 475 years return period [9] Sofia is in a region of PGA = 0.23 g and the vulnerability of the SWWTP "Kubratovo" is assessed for this PGA. During the design period of the plant Sofia is in 0,27g seismic zone [10].

Both methodologies give over 90% probability of being in or exceeding damage state "minor" and "none" for Sofia WWTP "Kubratovo" when it is classified as plant with anchored components (according to HAZUS) and low-rise RC building with low and high level of seismic design (the Greek project SRMLIFE). The HAZUS model gives 82% probability of "no damages" and 15% "minor" damage while the SMR LIFE model gives 11% "no damage" and 80% "minor" damage. That indicates the effect of building typology on the damage of the plant as a node of the system. The HAZUS model for unanchored components gives discrete probabilities Pds1/0.23g = 36%; Pds2/0.23g = 46%; Pds3/0.23g = 18%. For the SRMLIFE model of low rise RC building with low level of design the discrete probabilities are: P [D≥ds1/0.23g] = 11%; P [D≥ds2/0.23g] = 80%; P [D≥ds3/0.23g] = 0%, P [D≥ds4/0.23g] = 3% and P [D≥ds5/0.23g] = 6%. Among the four models considered the most vulnerable could be assumed the SRMLIFE model of low rise RC building with low level of seismic design as it gives probability of 6% of "complete" damage.



a) *b)*

Figure. 2 a) and b) Fragility curves for medium WWTP: a) HAZUS unanchored components and SRM LIFE low seismic level design of the RC building; b) HAZUS anchored components and SRM LIFE high seismic level design of low-rise RC building

The direct economic losses may be calculated based on the discrete probabilities, damage ratio provided by the methodology for each damage state for the WWTP [2] and the replacement value of the plant. The damage ratios in [1, 2] for the unanchored WWTR are listed in Table 3. First, the compound damage ratio is calculated. It is the sum of discrete probabilities multiplied by the respective damage ratio of each damage state. The compound damage ratio is listed in the last row of Table 3.

Table 3. Damage ratios for HAZUS medium capacity unanchored WWTP and SMR LIFE medium capacity WWTP with low code seismic design

Damage state	Damage ratio, HAZUS methodology		Damage ratio, SMR LIFE methodology
	Range	Best estimate	Range
Minor	0.01 to 0.15	0.1	0.1 to 0.3
Moderate	0.15 to 0.4	0.37	0.3 to 0.5
Extensive	0.4 to 0.8	0.65	0.5 to 0.75
Complete	0.8 to 1.0	1.0	0.75 to 1.0
Compound damage ratio	0.15 to 0.38	0.32	0.14 to 0.32

The compound ratio and the replacement value give the direct economic cost. Past studies in Bulgaria based on data from tenders for construction of urban WWTPs show that WWTP capital costs diminish with increasing the value of Population Equivalent /PE/ served (Fig. 3). The approximate prime capital cost for Sofia WWTP "Kubratovo" is calculated to be equal to 169 EUR/PE with 1313000 PE served. Hence, a rough estimate of the Sofia WWTP capital cost is about 221897000 EUR and hence, the direct economic loss is in the range 32000000 EUR to 84000000 EUR – to be affected by a possible earthquake in the area of Sofia with PGA = 0.23g.

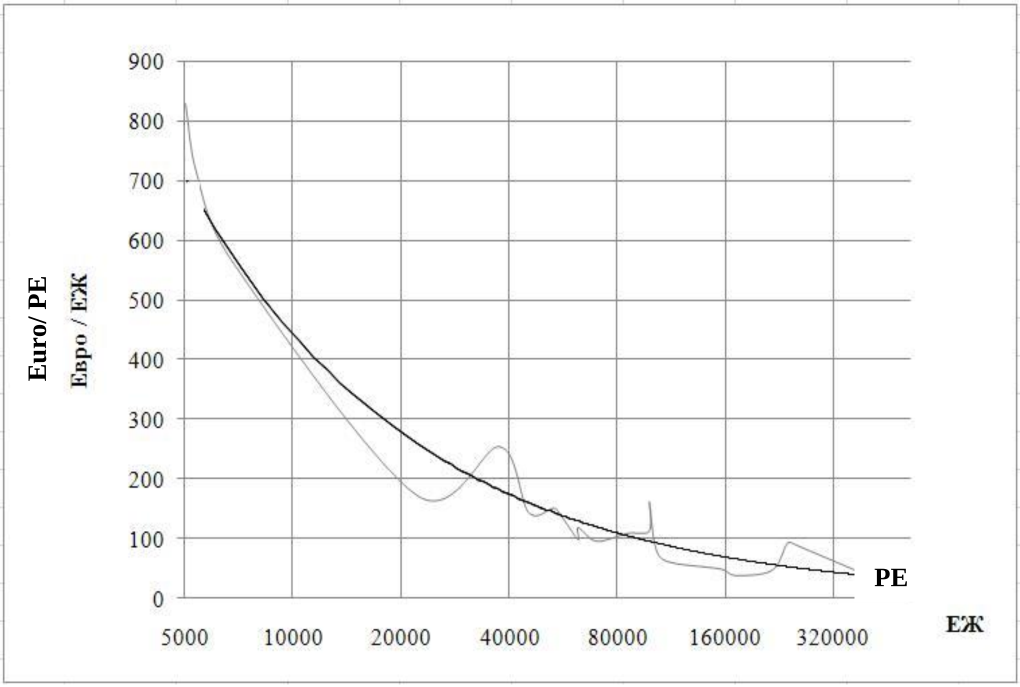
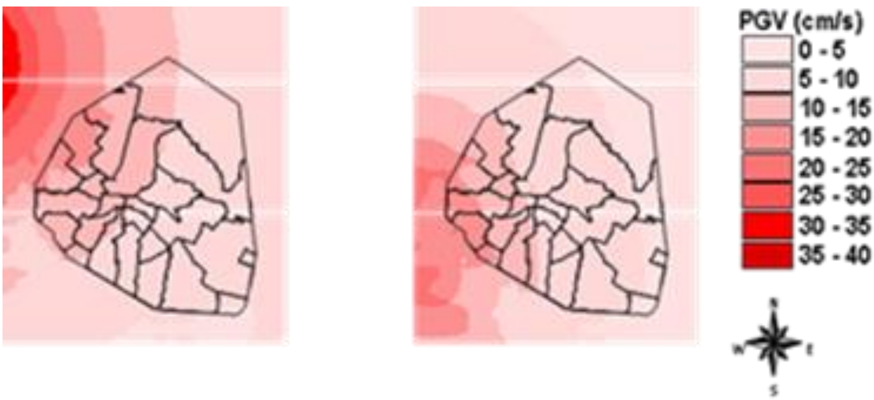


Figure 3. Bulgarian WWTP's capital costs versus value of Population Equivalent /PE/ served, Source: Aquapartner Ltd



a) M = 6.3 b) M = 5.5

Figure 4 a) and b). Maps of PGV for an earthquake of magnitude M = 6.3 and M = 5.5 [11]

For the case studied it is assumed that the wastewater network pipelines of Sofia are uniformly distributed in the city. So the length of pipelines is in proportion to the areas of the zones differentiated by the value of PGV (Fig. 4) [11]. The results based on the skeleton curves of the ALA and HAZUS methodologies (relations 2 and 1) and PGV distribution according to Fig. 4a) are summarized in Table 4.

The last row in Table 4 shows the total number of failures (defined with minimum and maximum PGV values for the zones). The highest value is 47 damages (breaks and leaks) in the wastewater network in case of an earthquake in Sofia region with magnitude M = 6.3 (Fig. 3a). This corresponds to average repair rate RR = 47/1660 = 0.03 repairs per km. For comparison, the number of leaks found in the wastewater network of Sofia during 2013 (“Sofiyska voda” webpage) is reported as 271 or RR = 0.16 repairs per km.

Table 4. Number of repairs (breaks and leaks) in the wastewater network pipelines of Sofia due to local earthquake of magnitude M=6.3 according to the skeleton curves of ALA and HAZUS

PGV	**L, km**	**Number of repairs, ALA**		**Number of repairs, HAZUS**	
		min	max	min	max
5 – 10 cm/sec	1245	15.3	30.5	4.7	22.1
11 – 15 cm/sec	332	9.0	12.2	7.3	14.7
16 – 20 cm/sec	83	3.2	4.1	4.2	7.0
Total	1660	27.5	46.8	16.2	43.8

7. Conclusions

In conclusion it should be underlined that for realistic assessment of expected damages in the wastewater treatment plants and pipeline network it is necessary that detailed specific data on the system components be collected. Data to carry out the hydraulic analysis, more precise GIS layout of the pipelines, collect nodes, regions with customers that are served by a collect node, specific data on the plants components and the building, system-specific fragility data, etc. should be included in the models. Analyses on the seismic behaviour of the structures, facilities and equipment in the systems should be carried out in order to be prepared in case of an earthquake and actions should be undertaken to reduce the seismic risk. At present the application of existing damage functions to the WW network gives a rough idea of the expected impacts and can only be used as initial information for preliminary studies.

Acknowledgements

This paper is elaborated within the NIGGG project “Development of a Method for Analysis, Assessment and Mapping of Seismic Risk in Republic of Bulgaria” financed by the Bulgarian Ministry of Regional Development and Public Works (MRDPW).

REFERENCES

1. *Pitilakis, K., Crowley, H., Kaynia, A. M.* Editors, SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk, Buildings, Lifelines, Transportation Networks and Critical Facilities, Springer, 2014.

2. FEMA, HAZUS-MH, Technical manual, Federal Emergency Management Agency, Washington DC, 2003.

3. (ALA) American Lifelines Alliance, Seismic Fragility Formulation for Water Systems, Part 1 and Part 2 – Appendices, 2001.

4. *O’Rourke, T. D., Toprak, S*. GIS Assessment of Water Supply Damage from the Northridge Earthquake. Geotechnical Special Publication 67, ASCE, 117-131, 1997.

5. *O’Rourke, T. D., Toprak, S., Sano Y.* Factors Affecting Water Supply Damage Caused by the Northridge Earthquake, Proceedings of the 6th U.S. National Conference on EE, 1-12, 1998.

6. SRMLIFE, 2003-2007, Development of a Global Methodology for the Vulnerability Assessment and Risk Management of Lifelines, Infrastructures and Critical Facilities. Research project, General Secretariat for Research and Technology, Greece.

7. MOEW, Analysis of the Water Economic Infrastructure, Annex 2, MoEW, National Strategy for Development of the Water Sector in the Republic of Bulgaria(in Bulgarian), 2015.

8. NSI, Data, Ecology_9.7, Ecology_9.6 (in Bulgarian).

9. BSS EN 1998-1 Eurocode 8 Design of Structures for Seismic Impacts (in Bulgarian).

10. NPSRC Standards for Design of Buildings and Facilities in Seismic Areas, 1964, Corrected Map of 1977 (in Bulgarian).

11. *Simeonova, S., Solakov D., Christoskov L.* Seismic Hazard, Application to Sofia, Part WG2 RISK-UE project 2003.

ОЦЕНКА НА СЕИЗМИЧНИЯ РИСК ЗА ЕЛЕМЕНТИ НА ТЕХНИЧЕСКАТА ИНФРАСТРУКТУРА – ОТПАДЪЧНИ ВОДИ

А. Канева[1], А. Ватралова[2]

Ключови думи: *оценка на сеизмичния риск, техническа инфраструктура, система отпадъчни води*

РЕЗЮМЕ

Въз основа на известни методологии в Европа и САЩ за оценка на сеизмичния риск са избрани модели за определяне на повредите в системата за отпадъчни води в България. Класификациите на компонентите на системата са анализирани с оглед на наличните у нас данни. Избраните модели са илюстрирани с конкретен пример и получените оценки са дискутирани.

[1] Антоанета Канева, доц. д-р инж., Департ. „Сеизмично инженерество“, НИГГГ-БАН, ул. „Акад. Г. Бончев“, бл. 3, София 1113, e-mail: akaneva[at]geophys.bas.bg; kaneva_ant[at]abv.bg

[2] Албена Ватралова, д-р гл. асист., секция „Водностопански изследвания”, НИМХ-БАН, бул. Цариградско шосе 66, София 1784, e-mail: albenav[at]bas.bg; albenav[at]mail.bg