STUDIA UBB AMBIENTUM, LXI, 1-2, 2016, pp. 57-72
(RECOMMENDED CITATION)

SEISMIC RISK ASSESSMENT FOR LARGE ROMANIAN DAMS ON BISTRITA AND SIRET RIVERS AND THEIR TRIBUTARIES

Iren-Adelina MOLDOVAN[1]*, Dragoş TOMA-DĂNILĂ[1], Angela Petruţa CONSTANTIN[1], Anica Otilia PLĂCINTĂ[1], Emilia POPESCU[1], Cristian GHIŢĂ[1], Mihail DIACONESCU[1], Traian MOLDOVEANU[2], Cosmin Marian PAERELE[3]

[1]National Institute for Earth Physics, Calugareni 12, 077125, Magurele, Ilfov;
[2]SC Geotec Consulting SRL, Vasile Lascar, no. 5-7, 020491, Bucharest;
[3]Administratia Bazinala de Apa Siret, Bacau;
**Corresponding author: irenutza_67@yahoo.com*

ABSTRACT. The most important specific requirements towards dams' safety is the seismic risk assessment. This objective will be accomplished by rating the dams into seismic risk classes using the theory of Bureau and Ballentine, 2002, and Bureau (2003), taking into account the maximum expected peak ground motions at dams' site, the structures vulnerability and the downstream risk characteristics. The maximum expected values for ground motions at dams' site have been obtained using probabilistic seismic hazard assessment approaches (PSHA) for dams situated on Bistrita and Siret Rivers and their tributaries. The structural vulnerability was obtained from dams' characteristics (age, high, water volume) and the downstream risk was assessed taking into account human, economical, touristic, historic and cultural heritage from the areas that might be flooded in the case of a dam failure. The results of the work consist of local and regional seismic information, specific characteristics and locations of dams, seismic hazard values and risk classes, for all sites. The studies realized in this paper have as final goal to provide in the near future the local emergency services with warnings of a potential dam failure and ensuing flood as a result of a large earthquake occurrence, allowing further public training for evacuation.

Key words: *earthquake, seismic hazard, risk classes, ground motion, dams*

INTRODUCTION

Not only humans but also dams are getting older. Dams, as all other constructions and infrastructures, are subject of ageing processes. The average age of Romania's 250 large dams tabulated in the Romanian Register of Large Dams (RRMB) from a total of 2617 permanent and temporary dams, is 40 years (http://www.baraje.ro/rrmb/rrmb_idx.htm). In Romania there are 3 dams more than 100 years old. The oldest one (111 years old), Sadu II, Sibiu, was put into operation in 1905, and is a small 18 m high gravity dam. More than 100 dams are in the immediate vicinity of populated areas, like the Morii Dam on Dambovita River in the Western part of Bucharest, the capital of Romania.

On Bistrita and Siret rivers, situated in the North - Eastern part of Romania, Moldavia Region, there are 22 large dams, built after 1960. Izvorul Muntelui dam (Bistrita river, very close to the city of Bicaz) is the largest one, with h=127 m and V lake=1230hm^3.

Although dams are built by following specific design and engineering rules regarding structural strength, serious dam accidents have occurred in the world, and also in Romania, in 1991 on Belci dam (Fig. 1 and 2) situated on Tazlau river that flows into Trotus river a tributary of Siret.

Fig. 1. *Belci dam, on Tazlau river, near Onesti city, Bacau county, Romania (Photo by Constantin Cristache, INCDFP, Romania)*

The story of Belci dam disaster is as follows:

During the night of 28th to 29th of July, 1991, torrential rainfall fell in the Tazlău river basin, with an unusual nature (between 95 l / m² and 150 l / m² in half an hour) that caused a flood wave of almost 7 meters tall near Belci dam, Bacau County (Diacon et al., 1992). Downstream Belci dam's micro-hydropower plant was stopped during that night due to a technical failure. Therefore it was stopped also the power supply for the dam's mechanisms.

Fig. 2. *The left bank of the Belci dam (Photo by Constantin Cristache, INCDFP, Romania)*

The water level in the lake increased very quickly, so that at 2:15 AM the water level reached the crest and started overflow the earth dam. Around 4:50 appeared an increase in the downstream flow at about 1,800 m^3/s, which led to the collapse of the dam. At 7:15 the lake was almost empty, and at 7:50 Tazlău river flowed through a fairway formed in the lake's alluvial deposits and passed downstream through a gap formed in the left bank of the earth dam (Figure 4). Maximum flow of the flood on the river Tazlău from 28^{th} to 29^{th} July 1991 was 3,100 cm/s (http://www.hidroconstructia.com/dyn/2pub/proiecte_det.php?id=112&pg=9). That summer morning, Slobozia, the little town downstream from the dam was flooded, 25 people died and 250 homes were destroyed.

These kind of events have occurred all over the globe, despite of the great attention paid to constructions behavior monitoring, due to various causes like acts of terrorism, dam structural problems, different errors during the exploitations or natural disasters such as: huge storms and associated runoff and flood events, slope failures, or earthquakes and landslides. Dams fracturing and collapsing in the last decades have caused thousands of casualties Worldwide, losses of hundreds of billions of dollars and destroying of entire downstream villages. ***The main mission of many international agencies and organizations is "To protect people against loss of life and property from dam failure."***

The present work, financed by UEFISCDI (Romania) PCCA 2013 Program, Project DARING 69/2014, is a step toward downstream safety assurance in the Eastern part of Romania. The paper will deal with probabilistic seismic hazard assessment in dams' sites, structure vulnerability and downstream risk evaluation, having as final goal the seismic risk rating of all 22 studied dams on Bistrita and Siret river and their tributaries.

METHODOLOGY FOR DAMS' RATING INTO SEISMIC RISK CLASSES

The methodology used in this paper offers a way to evaluate the most vulnerable hydro-technical facilities among the multitude of dams existing in a country that could be affected by crustal-depth or intermediate-depth earthquakes. Various risk factors and weighting points can be used to approximately quantify the Total Risk Factor (TRF) of any dam (Bureau and Ballentine, 2002 and Bureau, 2003). The TRF depends on the dam structure characteristics, the downstream risk potential, and the dam vulnerability.

This procedure can be used to quickly asses the potentially most vulnerable facilities in a large dam inventory. The risk classification based on the TRF, provides guidance to dam safety officials to select appropriate evaluation procedure and to assign priorities for seismic safety evaluation of the most critical dams.

The TRF is expressed as:

$$TRF = [(CRF + HRF + ARF) + DHF] \times PDF \qquad (1)$$

The dam structure influence is represented by the sum of capacity, height, and age risk factors (CRF + HRF + ARF). **The downstream hazard factor** (DHF) is based on population and property exposed at risk. **The vulnerability rating** is a function of the site-dependent seismic hazard and observed performance of similar dams, as defined by a predicted damage factor (PDF).

Dam structure Influence

There are three factors quantifying the risk of a dam and its reservoir:

1. The capacity risk factor (CRF) and the height risk factor (HRF) – that indicate that high dams or large reservoirs can cause significant flooding and an increased – Table 1.

Table 1. *Definition of capacity and height risk factors (Bureau and Ballentine, 2002)*

Risk factor	**Contribution to the total risk**			
	Extreme	**High**	**Moderate**	**Reduced**
Capacity (m^3)/**CRF**	>61.673.500/**6**	61.673.500-1.233.470/**4**	1.233.470-123.347/**2**	<123.347/**0**
Height (m)/**HRF**	>24,38/**6**	24,38-12,192/**4**	12,192-6,1/**2**	<6,1/**0**

2. The age rating factor (ARF) expresses that old dams are often more vulnerable than modern dams because of possible deterioration, lack of maintenance, use of obsolete modes of construction (concrete masonry or hydraulic fill), insufficient compaction, reservoir siltation, or insufficient foundation treatment (Bureau and Ballentine, 2002) – Table 2.

Table 2. *Definition of dam age risk factor (Bureau and Ballentine, 2002)*

Dam's age	**<1900**	**1900-1925**	**1925-1950**	**1950-1975**	**1975-2000**	**>2000**
ARF	6	5	4	3	2	1

Downstream Risk

The overall downstream hazard factor (DHF) is defined as:

$$DHF = ERF + DRI \quad (2)$$

The downstream evacuation requirements factor (ERF) depends on the human population exposed at risk. The downstream damage risk index (DRI) is based on the value of private, commercial, industrial, or government property in the potential flood path (Table 3). These factors should preferably be obtained from a combination of detailed dam breach, inundation mapping, and economic studies. The DHF should be updated whenever new information becomes available or when the dam is repaired, modified, or raised.

Table 3. *Definition of downstream risk factor DHF (Bureau and Ballentine, 2002)*

Risk factor	Contribution toTRF (share)			
	extreme	high	moderate	reduced
No. of people/ **ERF**	>1000/12	1000-100/8	100-1/4	0/1
DRI	high/12	moderate/8	reduced/4	none/1

Seismic Vulnerability Rating

Dam vulnerability curves developed by Bureau and Ballentine, 2002 from observed seismic performance of dams during earthquakes can be used to compute a predicted damage index (PDI). The PDI depends on the dam type and on the site seismic hazard and tectonic environment (Froehlich, 2008). The expected ground motion at the dam site for the scenario earthquake considered is expressed by the earthquake severity index (ESI), a robust estimate of the severity of shaking for dam evaluation purposes (Bureau, 2003).

The ESI is expressed as:

$$ESI=PGA*(M-4.5)^3 \quad (3)$$

Where: PGA is measured in *g*, M is the Richter or moment magnitude (*Mw,* if available) of the causative event.

The PDI depends on the ESI at each dam site, for each postulated earthquake scenario, and is obtained from graphical relationships shown in Fig. 3.

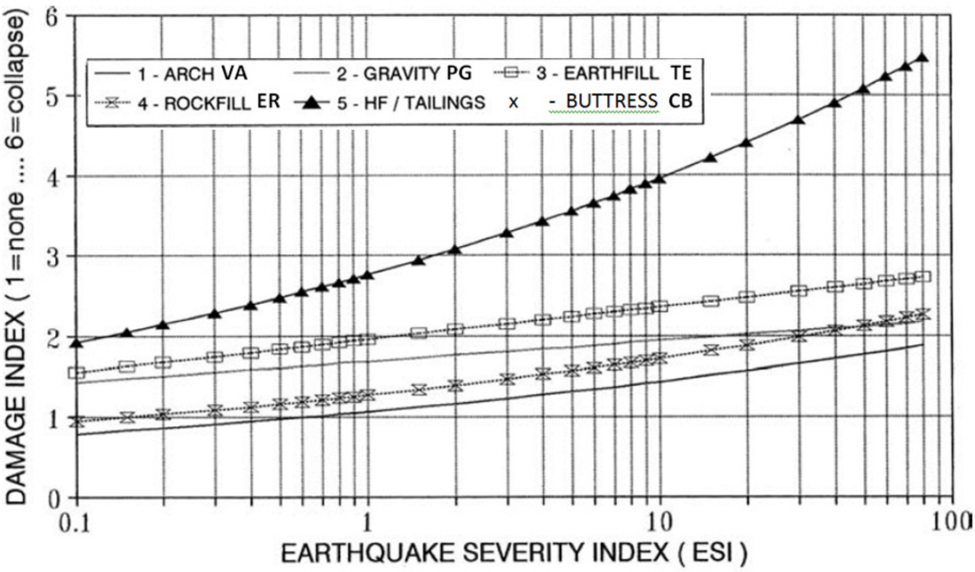

Fig. 3. *Dams' vulnerability curves*

The PDI rates only the relative vulnerability of each dam type, and includes a significant uncertainty, especially when extrapolated to large ESI values, which can be quantified from the standard deviations associated with the mean estimates.

Curve 1 corresponds to the dam's "Arc" type, curve 2 to "gravitational"-weight type, curve 3 to "earth filling" type, curve 4 corresponds to the embankment dams and curve 5 to the so-called hydraulic filled dams (hydraulic fill - HF). It appears that the most vulnerable are those of HF type (hydraulic fill), while "Arc" type dams had the best performance, but conclusions were drawn from a limited number of data. There are no information about buttress dams (CB) and we have used curve 3 for this type of dams.

As is well known, hydraulic fill and tailings dams are clearly the most severely affected, based on historic experience. Arch dams have performed best but the corresponding data are limited. From the graphical obtained PDI, a Predicted Damage Factor (PDF) is assigned to each dam, as defined by the equation (4):

$$PDF=2.5*PDI \quad (4)$$

After obtaining all risk factors (CRF, HRF, ARF, DHF and PDF), The TRF can be computed using Eq. 1. The last step of the assessment is to rank the dams by TRF and assign to each a Risk Class ranging from I (low risk) to IV (extreme risk), as shown in Table 4.

Table 4. *Definition of Dam Risk Classes*

TRF	Dam's risk class
2-25	I (reduced)
25-125	II (moderate)
125-250	III (high)
>250	IV (extreme)

The vulnerability and risk ranking of all Romanian dams (more than 250), was compiled in that way during the fulfilment of several National Projects. In this paper we will present the case of 22 large dams situated on Bistrita and Siret rivers, situated in the North - Eastern part of Romania, Moldavia Region.

RANKING LARGE DAMS ON BISTRITA AND SIRET RIVERS IN SEISMIC RISK CLASSES

The main source of information about studied dams was Romanian Register of Large Dams (RRMB) that contains information in Excell format regarding commissioning year, dimensions, characteristics, etc. for 249 dams in Romania. The information in RRMB were completed with existing information from Ro Water site (http://www.rowater.ro/dasiret/default.aspx). Table 5 and Fig. 4 present the 22 dams on Bistrita and Siret rivers and their tributaries.

Table 5. *Dams characteristics (Dams type is defined in Fig.3)*

Dam No.	Dam	Long	Lat	River	County	Year PIF	Type
1	ANTOHESTI	27.2381	46.5514	Berheci	Bacau	1984	TE
2	BACAU	26.9283	46.5573	Bistrita	Bacau	1966	PG/TE
3	BACAU	26.9235	46.5741	Bistrita	Bacau	1966	PG/TE
4	BELCI	26.7647	46.2882	Tazlau	Bacau	1963	PG/TE
5	BERESTI/ ROGOAZA	27.1860	46.1852	Siret	Bacau	1985	PG/TE
6	CALIMANESTI SIRET	27.2469	45.9486	Siret	Galati	1992	PG/TE
7	COSMESTI POD	27.3046	45.8578	Siret	Galati	2015	PG/TE
8	GALBENI	26.9569	46.4544	Siret	Bacau	1983	PG/TE
9	GARLENI	26.9549	46.6784	Bistrita	Bacau	1965	PG/TE
10	IZVORUL MUNTELUI	26.1030	46.9380	Bistrita	Neamt	1961	PG
11	LILIECI	26.8869	46.6306	Bistrita	Bacau	1965	PG/TE
12	MOVILENI	27.3430	45.7831	Siret	Galati		PG/TE
13	PANGARATI	26.2151	46.9259	Bistrita	Neamt	1965	PG/TE
14	PARAUL PANTEI	25.8224	47.1592	Bistrita	Neamt		PG/TE
15	PERESCHIV (Fichitesti)	27.4820	46.1670	Pereschiv	Bacau	1977	TE
16	PIATRA NEAMT (Batca Doamnei)	26.3431	46.9318	Bistrita	Neamt	1963	PG/TE
17	POIANA UZULUI	26.3923	46.3359	Uz	Bacau	1973	CB
18	RACACIUNI	27.0479	46.3340	Siret	Bacau	1984	PG/TE
19	RACOVA	26.7174	46.6916	Bistrita	Bacau	1965	PG/TE
20	TASCA BICAZ	26.0009	46.8866	Bicaz	Neamt	1980	PG/TE
21	TOPOLICENI	25.9230	47.1122	Bistrita	Neamt		PG/TE
22	VADURI	26.2559	46.9392	Bistrita	Neamt	1965	PG/TE

Risk related to structure

For the 22 dams, besides the exact determination of the geographical coordinates there have been determined also information about construction features required in calculating seismic risk: the year of commissioning (PIF in Table 7), type of dam, dam height (in meters) and volume of the lake in hm^3 (millions of m^3) (Table 7). Using this information, in Table 7 are also presented the risk factors due to age (ARF), height (HRF) and lake capacity (CRF).

The downstream risk (DHF)

The risk factor of the downstream water accumulations, take into account the dams location, the villages located downstream, the distance and the height difference between them, the number of inhabitants which should be evacuated and the existing infrastructure (hydro-energetic plants, roads, highways and gas stations, railroad stations, widely populated and visited tourist attractions).

In order to calculate the downstream risk factor, different scenarios were realized regarding flooding areas downstream from dams. There were identified the nearest studied dams' locations, the number of inhabitants (Table 6) and were obtained information regarding the value of downstream properties. Transposing this information in risk factors was done in Table 7. The information related to downstream towns were taken from city halls internet sites and Wikipedia.

Table 6. *Downstream situation*

Dam No	H1 (m)*	Downstream locality	County	H2 (m) **	I2-H1 (m)	Dist (km)	INFO LOCALITY						
							Popula-tion	N° house holds	N° housing	Principal econ activities	1	2	3
1	210	Antohesti	Bacau	210	0	0	258	150	167	Agriculture and fishing	N	N	N
2	152	Bacau	Bacau	152	0	0	144500	56503	67715	Industry	D	D	D
3	157	Bacau	Bacau	157	0	0	144500	56503	67715	Industry	D	D	D
4	199	Belci, Slobozia	Bacau	192	7	1.6	268	-	-	-	N	N	N
5	102	Costisa	Bacau	100	2	1.7	1336	-	-	-	D	D	N
6	70	Malureni	Galati	150	-80	2.7	199	-	-	-	N	N	N
8	136	Galbeni	Bacau	136	0	0.9	826	-	-	-	D	D	N
9	190	Surina	Bacau	188	2	0.7	227	-	-	-	N	N	N
10	532	Dodeni	Neamt	427	105	1.4	1654	-	-	-	D	D	N
11	172	Lilieci	Bacau	172	0	1.1	2483	-	-	-	D	D	N
12	39	Movileni	Galati	38	1	1.7	3269	1168	941	Agriculture	D	D	N
13	360	Pangarati	Neamt	360	0	0.3	5170	1780	1720	Wood manufacture	D	D	N
14	564	Stejaru	Neamt	562	2	0.1	674	-	-	-	D	D	N
15	91	Plesesti	Bacau	110	19	2.9	103	-	-	-	N	N	N
16	324	Piatra Neamt	Neamt	315	9	0.1	104000	4500	36500	Tourism Industry	D	D	D

17	472	Salatruc	Bacau	414	58	1.2	854	-	-	-	D	D	N
18	123	Rastoaca	Bacau	117	6	0.5	106	-	-	-	N	N	N
19	203	Racova	Bacau	202	1	1.4	3602	1284	1284	Agriculture	D	D	N
20	521	Ticos Floarea	Neamt	516	5	0.7	349	-	-	-	N	N	N
21	523	Poiana Teiului	Neamt	520	3	0.2	4344	1596	1878	Agriculture	D	D	N
22	346	Vadurele	Neamt	345	1	0.1	252	-	-	-	N	N	N

* H1 Altitude Dam (m)/ ** H2 Altitude locality (m) /1. School / 2. Railway Station/ 3. Factory

Table 7. *Dams risk factors*

No.	ID	Dam	H (m)	Vlake (hm^3)	No. Loc av	ARF	HRF	CRF	ERF	DRI	ΣFs +DHF
1	1	ANTOHESTI	7	1	258	2	2	2	8	4	18
2	3	BACAU	18.0	4.0	144500	3	4	4	12	12	35
3	4	BACAU (Serbanesti)	18.0	4.0	144500	3	4	4	12	12	35
4	6	BELCI	16.0	12.5	268	3	4	4	8	4	23
5	7	BERESTI/ROGOAZA	29.0	120.0	1336	2	6	6	12	4	30
6	10	CALIMANESTI SIRET	22.5	44.3	199	2	4	4	8	4	22
7	22	COSMESTI POD	20.0	17.0	162	1	4	4	8	4	21
8	34	GALBENI	24.0	39.6	826	2	4	4	8	4	22
9	35	GARLENI	19.0	5.1	227	3	4	4	8	4	23
10	38	IZVORUL MUNTELUI	127.0	1230.0	1654	3	6	6	12	4	31
11	39	LILIECI	19.0	7.4	2483	3	4	4	12	4	27
12	44	MOVILENI	21.5	63.6	3269	1	4	6	12	4	27
13	46	PANGARATI	28.0	6.0	5170	3	6	4	12	4	29
14	47	PARAUL PANTEI	19.5	1.0	674	2	4	2	8	4	20
15	50	PERESCHIV (Fichitesti)	13.0	16.5	103	3	4	4	4	4	19
16	51	PIATRA NEAMT (Batca Doamnei)	27.0	10.0	104000	3	6	4	12	12	37
17	54	POIANA UZULUI	80.0	88.0	854	3	6	6	8	4	27
18	58	RACACIUNI	29.0	103.7	106	2	6	6	4	4	22
19	59	RACOVA	20.0	8.7	3602	3	4	4	12	4	27
20	71	TASCA BICAZ	19.5	0.3	349	2	4	2	8	4	20
21	72	TOPOLICENI	19.5	0.1	4344	1	4	0	12	4	21
22	75	VADURI	27.0	5.6	252	3	6	4	8	4	25

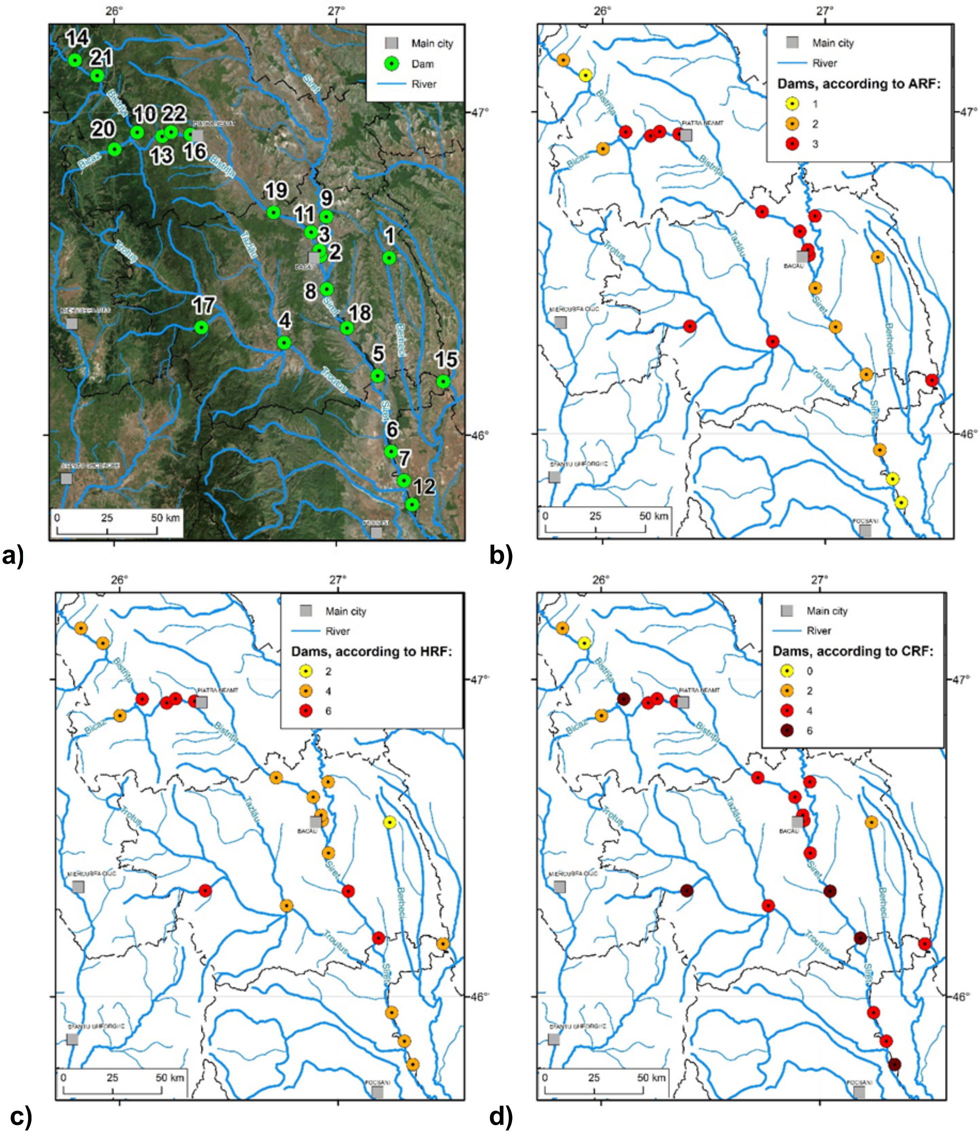

Fig. 4. *a) Location of the dams in Table 6, with id's as labels; b) Dam characterization according to age (ARF), c) height (HRF) and d) accumulation lake capacity (CRF) classes mentioned previously*

Seismic Vulnerability Rating - the predicted damage factor (PDF)

Dam vulnerability curves, curves developed by the Bureau and Ballentine (2002) using dams seismic performance observed during earthquakes can be used to calculate the predicted damage index (PDI). PDI depends on the type of dams, seismic hazard and tectonic environment. Expected maximum amplitude of soil movement in dam sites is expressed through earthquake severity index (ESI), which gives us a robust estimation of the severity of possible movement in site, in order to evaluate the dam (Bureau, 2003).

Seismic hazard evaluation in dam sites

A key milestone in the development of PSHA was the computer program EQRISK, written by McGuire (1976). A version of machine code EQRISK (McGuire, 1976) improved by Leydeker et al. 2008 was formerly used in practice for probabilistic hazard assessment in Romania (Moldovan et al., 2008 and Moldovan et al., 2012). The code is widely distributed, and today is still the most frequently used hazard software, and has led to PSHA often being referred to as Cornell (Cornell, 1968) - McGuire method.

Figure 5 and Table 8 show the characteristics of all seismic sources used for probabilistic evaluation of hazard (Leydecker et al., 2008 and Moldovan et al., 2016). With the input parameters as defined in Table 8 for the five selected sources which likely affect the chosen area we estimated seismic hazard values for different return periods (Tr = 1, 50, 100, 475 and 1000 years) and also the expected Modified Mercalli Intensity (MMI) values for the same time intervals. The computations were performed in the sites of dams from Table 5. The conversion between ***I*** and ***PGA*** (peak ground acceleration) is given, for Vrancea intermediate earthquakes by Sorensen et al., 2008:

$$I = 4.48 \log (PGA) + 6.55$$ where PGA is expressed in m / s^2.

Table 8. *The statistical parameters used for probabilistic evaluation of regional and local seismic hazard and dams' sites*

Source	Coordinates		Average depth (km)	M min (Mw)	M max (Mw)	b	I min	I max	bi	β i= =bln10	Seismic ctivity rat
VRI	45.65	26.15	130	5.0	7.9	0.85	4.0	10	0.48	1.12183	1.762380
	45.4	26.5									
	45.85	27.05			7.7			10			
	46.05	26.6									
VN	45.44	25.65	30	3.0	5.9	0.95	2.5	7.0	0.6	1.38155	0.514526
	46.22	26.70									
	45.75	27.90			5.5			6.0			
	44.90	27.00									
BD	46.22	26.70	10	2.5	5.5	0.75	2.0	6.5	0.49	1.12826	1.534712
	46.7	26.8									
	46.6	27.8									
	45.79	27.66									
PD	45.23	27.60	10	3.0	5.5	0.81	3.0	6.5	0.53	1.22405	0.360254
	45.75	27.90									
	45.2	29.3									
	44.67	28.74									

For seismic risk studies, the intensity and acceleration values for a recurrence period of 475 years were considered, which corresponds to a exceeding probability of 10% in 50 years or 0.2% in a year. These values are presented in Table 10. In Figure 6 we have represented the maximum possible accelerations (for Tr = 475) in 22 dams' sites in Eastern Romania.

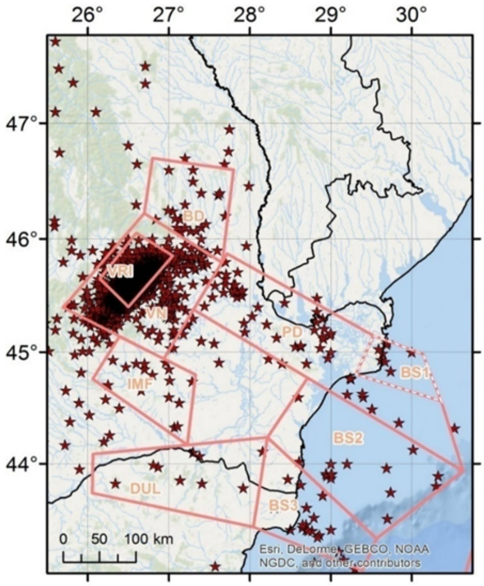

Fig. 5. *Seismic zoning - Seismicity was represented only for earthquakes with Mw> 3.5 (Moldovan et al, 2016)*

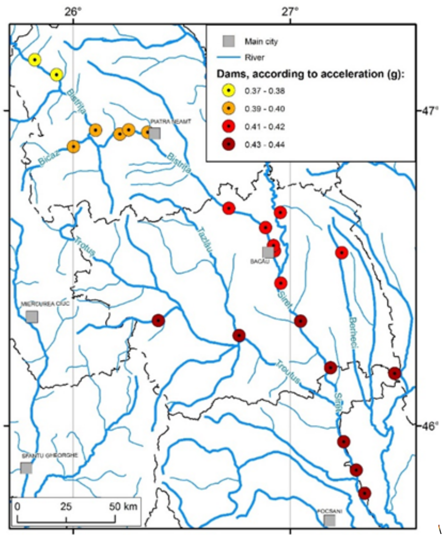

Fig. 6. *Maximum possible accelerations (Tr = 475 years) in sites for 78 dams in Eastern Romania*

To calculate predicted losses PDF factor, we needed information on seismic hazard (the maximum possible acceleration in g units and the maximum earthquake magnitude associated with this acceleration) and the specific vulnerability curves for various types of dams (Figure 5). For the 22 studied dams it was concluded that Vrancea intermediate earthquakes influence the seismic hazard in the most powerful way. This means that Mmax from the equation 3 will be given by Vrancea intermediate earthquakes and will be Mw max = 7.7. ESI index from the same equation (3): ESI = $PGA \times (M_w - 4.5)^3$ is calculated as well in Table 9.

Considering the dam's type, the PDI indices were found from the graphs in Figure 3. All 4 graphics were digitized for quick calculation of the ESI- PDI correspondence. Using PDI values obtained from the graph in Figure 3, we calculated the PDF of every dam using the relation 4. PDI and PDF are both given in Table 9.

Table 9. *Expected maximum acceleration values (in g units) in dams locations, for Tr = 475 years, earthquake magnitude that led to this acceleration and the calculated values of ESI, PDI and PDF*

Dam No	I	a (g)	Mw max	ESI	Dam type	PDI	PDF
1	9.5	0.407	7.7	13.325	TE	2.396	5.990
2	9.5	0.413	7.7	13.532	PG/TE	2.398	5.995
3	9.5	0.411	7.7	13.463	PG/TE	2.397	5.993
4	9.5	0.433	7.7	14.173	PG/TE	2.408	6.020
5	9.5	0.430	7.7	14.100	PG/TE	2.398	5.995
6	9.5	0.439	7.7	14.393	PG/TE	2.413	6.033
7	9.5	0.442	7.7	14.467	PG/TE	2.414	6.035
8	9.5	0.419	7.7	13.742	PG/TE	2.4	6.000
9	9.5	0.402	7.7	13.189	PG/TE	2.394	5.985
10	9.0	0.384	7.7	12.593	PG	1.965	4.913
11	9.5	0.407	7.7	13.325	PG/TE	2.396	5.990
12	9.5	0.442	7.7	14.467	PG/TE	2.414	6.035
13	9.0	0.386	7.7	12.658	PG/TE	2.388	5.970
14	9.0	0.367	7.7	12.023	PG/TE	2.378	5.945
15	9.5	0.422	7.7	13.813	TE	2.408	6.020
16	9.0	0.386	7.7	12.658	PG/TE	2.388	5.970
17	9.5	0.428	7.7	14.028	TE	2.404	6.010
18	9.5	0.426	7.7	13.956	PG/TE	2.408	6.020
19	9.5	0.405	7.7	13.257	PG/TE	2.394	5.985
20	9.0	0.386	7.7	12.658	PG/TE	2.388	5.970
21	9.0	0.371	7.7	12.148	PG/TE	2.382	5.955
22	9.0	0.384	7.7	12.593	PG/TE	2.386	5.965

Dams rating in seismic risk classes

After finding all the risk factors and the PDF value (Tables 6 and 8), we have calculated with Equation 1, the total risk factor, TRF (Table 10). Using risk class definitions in Table 4, we have rated in risk classes the 22 studied dams (Table 10).

Table 10. *Dams rating into risk seismic classes*

Dam No	$\sum F$ + DHF	**PDF**	**TRF**	**Risk Class**	**Risk Type**
1	18	5.990	107.82	II	Moderate
2	**35**	**5.995**	**209.83**	**III**	**High**
3	**35**	**5.993**	**209.74**	**III**	**High**
4	23	6.020	138.46	III	High
5	30	5.995	179.85	III	High
6	22	6.033	132.72	III	High
7	21	6.035	126.74	III	High
8	22	6.000	132.00	III	High
9	23	5.985	137.66	III	High
10	31	4.913	152.29	III	High
11	27	5.990	161.73	III	High
12	27	6.035	162.95	III	High
13	29	5.970	173.13	III	High
14	20	5.945	118.90	II	Moderate
15	19	6.020	114.38	II	Moderate
16	**37**	**5.970**	**220.89**	**III**	**High**
17	27	6.010	162.27	III	High
18	22	6.020	132.44	III	High
19	27	5.985	161.60	III	High
20	20	5.970	119.40	II	Moderate
21	21	5.955	125.06	III	High
22	25	5.965	149.13	III	High

CONCLUSIONS

From 22 dams studied in this article, only 4 are ranked in the moderate risk class (II). The rest are rated in the high risk class with total risk factor values between 125 and 220. None of the dams from Siret and Bistrita rivers were included in extreme seismic risk class, which would have been obtained for a TRF= 250. Three dams had however higher TRF values than 200, namely: Bacau (two dams) and Piatra Neamt. Seismic risk calculations were performed for a return period of 475 years, corresponding to a probability of 0.2% a year.

If it will evaluate the risk for Tr = 1,000 years, the 3 aforementioned dams could pass into a higher class of risk. But the legislation does not require return high periods than in nuclear power plants (Tr = 10,000 years), estimates being sufficient for dams for Tr = 475 years.

ACKNOWLEDGEMENT

This work is supported from PCCA 2013 Project DARING 69/2014, financed by UEFISCDI, Romania.

REFERENCES

Bureau G.J., 2003, Dams and appurtenant facilities, in *"Earthquake Engineering Handbook"*, CRS Press, WF Chen, and C Scawthorn (eds.), Boca Raton, pp. 26.1-26.47.

Bureau G.J., Ballentine G.D., 2002, A comprehensive seismic vulnerability and loss assessment of the State of Carolina using HAZUS. Part IV: Dam inventory and vulnerability assessment methodology, *7th National Conference on Earthquake Engineering*, July 21-25, Boston, Earthquake Engineering Research Institute, Oakland, CA (CD ROM).

Cornell C.A., 1968, Engineering seismic risk analysis. *Bull. Seism. Soc. Am*, **58** (5), pp. 1583-1606.

Diacon A., Stematiu D, Mircea N., 1992, An analysis of the Belci dam failure. *Water Power & Dam Construction* - September 1992.

Froehlich D.C., 2008, Embankment Dam Breach Parameters and Their Uncertainties. *Journal of Hydraulic Engineering*, **134** (12), pp. 1708-1720.

Leydecker G., Bushe H., Boyner K. P., Schmitt T., Kaiser D., Simeonova S., Solakov D., Ardeleanu L., 2008, Probabilistic Seismic Hazard in Terms of Intensities for Bulgaria and Romana-Updates hazard maps. *Hazards and Earth System Science*, **8**, pp. 1431-1439.

McGuire R.K., 1976, FORTRAN computer program for seismic risk analysis. *U.S. Geological Survey Open-File Report* 76-67.

Moldovan I.A., Popescu E., Constantin A. P., 2008, Probabilistic seismic hazard assessment in Romania: Application for crustal seismic active zones. *Rom. Journ. of Phys.,* **53** (3-4), pp. 575-591.

Moldovan I.A., Constantin A.P., Popescu E., Placinta A.O., 2012, Earthquake risk classes for dams situated in the South-Western part of Romania (Danube, Olt, Jiu and Lotru rivers). *Romanian Report in Physics*, **64** (2), pp. 591-608.

Moldovan I.A., Diaconescu M., Popescu E., Radulian M., Toma-Danila D., Constantin A.P., Placinta A.O., 2016, Input Parameters for the Probabilistic Seismic Hazard Assessment in the Eastern Part of Romania and Black Sea Area. *Rom. Journ. Phys.*, **61** (7-8), pp. 1412-1425.

Sorensen, M.B., Stromeyer D., Grünthal G., 2008, Estimation Of Macroseismic Intensity – New Attenuation And Intensity Vs. Ground Motion Relations For Different Parts Of Europe, The 14 Third World Conference On Earthquake Engineering October 12-17, 2008, Beijing, China.

*** http://www.rowater.ro/dasiret/default.aspx

*** http://www.hidroconstructia.com/dyn/2pub/proiecte_det.php?id=112&pg=9

*** RRMB - http://www.baraje.ro/rrmb/rrmb_idx.htm