京都大学防災研究所年報 第 54 号 B 平成 23 年 6 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 54 B, 2011

Possible Scenarios for Rjecina River Catchment – on the Example of Grohovo Landslide

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Synopsis

Rjecina river is an example of a large torrential watercourse typical for the coastal karst zone of Croatia with its river mouth in the center of Rijeka city. The central part of the watercourse is the most unstable part of the valley, with the highest degree of geological hazard. Here, mass movements are occurring mainly at the contact of carbonate rocks with the flysch rock complex. There are historic data of few rockfalls and landslides on both slopes of the valley. A potential geohazard event could involve movement of slope deposits towards the channel of the Rjecina River. Heavy precipitation and/or earthquakes may be potential triggers of rockfalls and rockslides. So there is a possibility of massive scale landslide occurrence and consequently it can cause several scenarios. Possible scenarios would be investigated furtherly during the Croatia-Japan Joint Project. The paper shows the basic modeling approach for Scenario for Massive scale debris flow occurrence.

Keywords: landslide, debris flow, flysch, rainfall event

1. Introduction

Rjecina watercourse, in the northwestern Adriatic part of Croatia (Fig. 1a), is large torrential watercourse with its river mouth located in the center of the city of Rijeka (Fig. 1b). The central part of the watercourse, is the most unstable part of the valley. Here, mass movements are occurring mainly at the contact of carbonate rocks with the flysch rock complex. There are historic data of few rockfalls and landslides on both slopes of the valley. A potential geohazard event could involve movement of slope deposits towards the channel of the Rjecina River. Heavy precipitation and/ or earthquakes may be potential triggers of rockfalls and rockslides.

The historic data showed strong correlation of flood/ rainfall events with mass movements (rockfalls and landslides), so, there is a need for estimation of flood and other related hazards in the area (particularly landslide and debris flow hazard).

Based on the dominant active process debris flows can be subdivided into three sections: a source area, a transport area and a depositional area 7). Four environments can be identified as source areas: landslide deposits, highly fractured rocks, scree or talus deposits, and glacial deposits 6). So, there is a possibility of massive-scale debris flow occurrence as a consequence of Massive Scale Landslide Occurrence and large discharge of Rjecina River. Debris Flow hazard will be defined by: Observation of surface and sub-surface flow during the flood events; Development of numerical modeling for Debris Flow and Mass-scale landslide and Development of Early-warning system for the whole Rjecina river Basin.

Fig.1a. Location map of Rjecina river

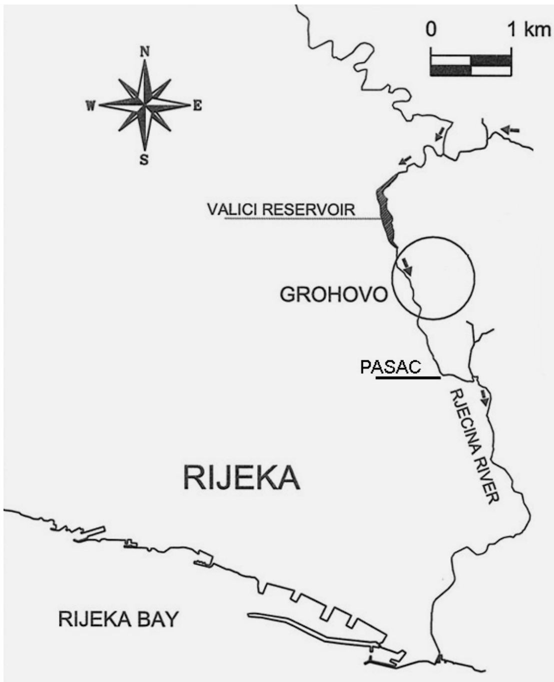

Fig.1b. Location map of Rjecina and Grohovo landslide

Rjecina river Basin and Landslide Grohovo will be investigated as one of pilot areas in Croatia-Japan Joint Project "Risk identification and land-use planning for disaster mitigation of landslides and floods in Croatia". The project should result in defining hazards for pilot areas.

Possible scenarios are defined (Table 1) and would be investigated furtherly during the Project. This paper shows the basic modeling approach for Scenario 1 (Scenario for Massive scale debris flow occurrence).

Table 1 Possible scenarios for Rjecina River and Grohovo Landslide

OCCURRENCE OF MASSIVE SCALE LANDSLIDE		
YES (There is Massive Scale Landslide Occurrence)		
Rjecina River Discharge	Large	Massive-scale debris flow occurrence
	Small	Formation of natural dam and dam break
NO (There is No Massive Scale Landslide Occurrence)		
Surface flow	Large	Threshold for occurrence of surface landslide
	Small	Determination of threshold for the occurrence of surface flow

2. Description of study area

Mean annual precipitation (MAP) depends largely on morphological characteristics of the area. In the mountainous areas MAP is up to 3500 mm, while closer to coastal part of wider area of Rijeka it decreases to 1750 mm. MAP for the station Rijeka (located in the most downstream part of Rjecina river) is 1534 mm. Significant very intensive but short-term rainfall events has the major influence on water discharge for surface, as well as for groundwater's.

The wet season lasts from September to January, with dry season from May to August. The whole area is occasionally subject to very intense rainstorms, which can cause serious damage by flash floods and mass movements. Daily precipitations of 100 mm and more are relatively frequent in the area. Due to that, the surface flows of the study area have torrential characteristics. Characteristics and morphogenesis of Rjecina River are described in the following text.

2.1. Characteristics of the Rjecina river and the flood control problem

The Rjecina river is an example of a large torrential watercourse typical for the coastal karst zone of Croatia. It is a typical karstic river originating from a strong karstic spring located at the foot of Gorski Kotar Mountains. Majority of Rjecina river discharge are coming from the strong karst spring occurring at 325 m above sea level. The watercourse is 18.63 km long and has the direct (orographic) catchment area of app. 76 km2 , but the catchment area of all sources that nourish Rjecina and its tributaries is much larger, app. 400 km2.

Part of the water balance from the Rjecina spring is used for water supply of Rijeka, while part of the water from the Valici reservoir is used for electric power production in the hydroelectric power plant of Rijeka. The annual average flow of the Rjecina spring is 7.8 m3s-1 with maximal flow rates ranging from 0 to over 100 m3s-1 1). This regular annual drought periods are usually occurring during summer and are lasting from 1 to 4 months.

The Rjecina has a few tributaries, the most important being the Susica River. Susica River is a left bank tributary with an annual average flow of 0.72 m3s-1. Although dry for most of the year, the maximal flow of the Susica can reach 43.8 m3s-1.

The longitudinal slope of the watercourse varies from 1.0% in the upper part, 3.0% in the central part, to minimum 0,36% in the lower part. Rjecina riverbed from the Valici reservoir to Pasac bridge belongs to central part of the river valley. From Pasac bridge to center of Rijeka it flows through the canyon. Due to the geological composition and morphology, the central part is the most unstable part of the valley.

The discharge varies greatly during the year, from the minimum of 0 m3/s in the profile directly below the spring (during summer months for about 30 days up to 3 months) to the maximum ever recorded 439 m3/s at the river mouth profile (calculated on the basis of observations during the disastrous flood on September 19, 1898).

After the great floods in late 19th century, the river mouth was displaced and corresponding regulation works were carried out. The lowest downstream part of the river and its river mouth were displaced after the great flood in 1852 5). After the catastrophic flood in 1898. extensive channel regulation was performed in the upper central part of Rjecina watercourse. The majority of regulation works were done to reduce flood effects, consisting of transversal structures (water steps) in order to prevent deepening of the channel and formation of landslides.

For hydropower purposes, the hydropower plant Rijeka was constructed in 1968, which uses water from the Valici reservoir (useful capacity 0.7 million m3) located in the middle part of the valley.

To show the changes in water regime of Rjecina river after the reservoir (dam) construction, discharge for the Grohovo profile (downstream from the dam) before (up to 1967) and after (starting from 1969) the construction of the dam are shown on the Fig. 2.

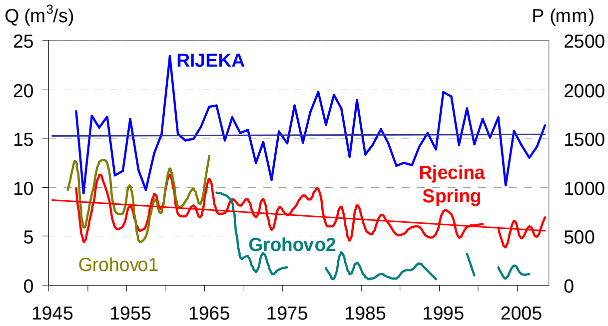

Fig. 2. Changes in the water regime before and after the construction of dam in 1968. Mean annual flow (m3/s) is shown for two profiles (Rjecina Spring and Grohovo) and MAP for Rijeka station (mm), for the period 1947-2007.

2.2. Morphogenesis of the Rjecina valley/ Geological composition and slope morphogenesis

Rjecina River extends through two distinctive geomorphological units. The upstream and central part of the river valley is relatively narrow and formed in flysch and limestone. Cretaceous and Paleogene limestone rocks are situated on the top of the slopes, while Paleogene flysch forms the lower parts, including the bottom of the valley. The downstream part of the watercourse flows through deep canyon cut into the Cretaceous and Paleogene carbonate rocks 2).

Limestone rock mass is faulted and extensively fractured which enabled separation of mega-blocks, disintegration of the rock mass and the accumulation of talus at the foot of the mega-blocks. Unlike the limestones, the flysch rock mass is more prone to weathering, particularly silts, marl and shales which are predominant in the flysch. Thus, a clayey weathering zone formed in the flysch bedrock. In time, coarse-grained fragments originating from talus were mixed with clay from the flysch weathered zone and slope deposits several meters thick were formed. Such a sequence of the morphogenetic events caused potentially unstable slope formations.

The complex landslide origin is preconditioned by geological structure and morphogenesis of the Rjecina River valley. Rjecina River valley is geomorphologically younger compared to other nearby valleys formed in flysch. Due to such geological and morphological conditions, both slopes in Rjecina river valley between Valici reservoir and Pasac are at the edge of stable equilibrium state. Historic records of landsliding during 19th and 20th century are giving proof for this.

3. Landslide description

The investigated landslide is situated at the northeastern slope of Rjecina river valley (Fig. 1). Slopes in Rjecina valley between Valici dam and Pasac are at the edge of stable equilibrium state, so several greater landslides were recorded during 19th and 20th century (the larges one after the big flood in 1898). The investigated landslide area is not a recent phenomenon, either. Initial slide body moved several times with the most recent larger displacement observed on December 5, 1996 and the very next day Rjecina riverbed was almost entirely partitioned off. After the initial landslide shift, there was a retrogressive advance from toe to head, as well as formation of the smaller landslides. At the end of the process, isolated rocky blocks were moved, and rocky scarps fractures on the slope head opened.

The field investigations indicated a complex landslide and evidence of many individual movements could be distinguished. Thirteen separate slide bodies have been identified.. Monitoring indicated that the magnitude of displacements was very different in time and space. The maximum movements were recorded on the upper part of the slope. The limestone mega-block and separated rocky blocks on top of the slope have also moved, which is not a typical phenomenon of the flysch slopes in the area of Rijeka 3).

Estimated dimensions and geometry of this instability are 4):

- total length: L = 425 m;
- width of the displaced mass: Wd = 200 m;
- depth of the displaced mass: Dd = 6-20 m;

4. Historical Rainfall Events And Landslide Occurrence

Slope failures can be triggered by a single event, such as an earthquake; rainstorm or prolonged rainfall period and a snowmelt. Depending on meteorological and physiographical conditions, individual rainfall event can cause slope failures in areas of limited extent or in large regions.

Historic data for the area of Rijeka, record more flood events and some of them with catastrophic damages. The occurrence of floods in the historic records are closely related to occurence of rockfalls and landslides in the study area. In 1870. part of the hill under the village Gohovo collapsed and coused damages to many houses and water steps. In 1885 after the long rainy period, Grohovo landslide was reactivated and moved the slope of 500 m length and 80 m height, causing severe damage by destroying the entire village. The landslide was reactivated several times in the next fifteen years. The biggest movement happened in November 1898. when the major part of the slope moved toward the Rjecina river. This landsliding happened after the disastrous flood in October 1898. This flood was caused by heavy rain on 19th October 1898 when 222 mm of rain during 3.5 hours formed a catastrophic flood wave with the estimated flow of 439 m3s-1, that is, more than 100-year return period high water for the Rjecina River.

The most recent larger displacement of Grohovo landslide was observed on December 5, 1996. The landslide was triggered by longer rainy period that lasted for few months. In the period, the regional mean annual precipitation (MAP) was 1929 mm, 26 % higher than the average MAP for the period between 1948 and 2009.

The autumn and early winter of 1996. were particularly wet in the Rijeka Region. Long rainy period resulted in a cumulative rainfall in the period from October to December exceeding 900 mm which is app. 75 % higher compered to the average cumulative rainfall (519 mm) calculated for the same period (Oct- Dec) in the period between 1948 and 2009.

Figure 3. shows the cumulative rainfall measured at the Rijeka rain gauge in October, November, and December, 1996. In the considered period, the monthly rainfall was from 94% (October) to 64 % (November) higher than the average monthly values in the period form 1948 to 2009 (red lines in Fig 3).

Analysis of the available historical record indicates that monthly rainfall at the Rijeka rain gauge exceeded 200 mm more then 20 times in the period from September to December, with a maximum monthly value of 526,7 mm in October 1998 (Fig 4).

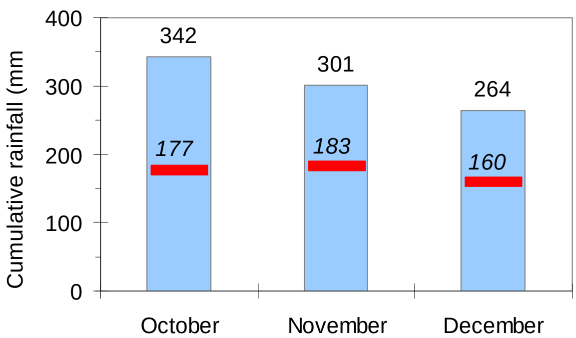

Fig. 3. Bars show cumulative rainfall at the Rijeka rain gauge for October, November, and December 1996. Red lines and italic numbers show long-term (1948–2009) monthly averages.

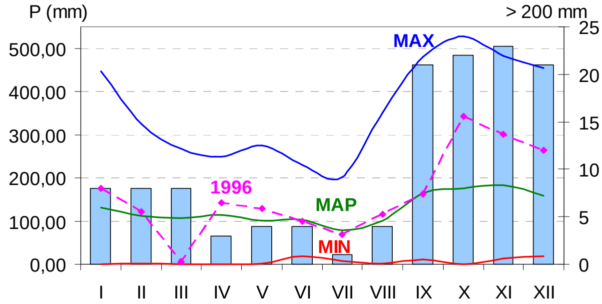

Fig. 4. Bars show number of events when monthly rainfall exceeds 200 mm. Lines showing mean annual precipitation (MAP), minimum annual precipitation (MIN) and maximum annual precipitation (MAX) for the period 1948–2009. Violet line shows annual flow for 1996.

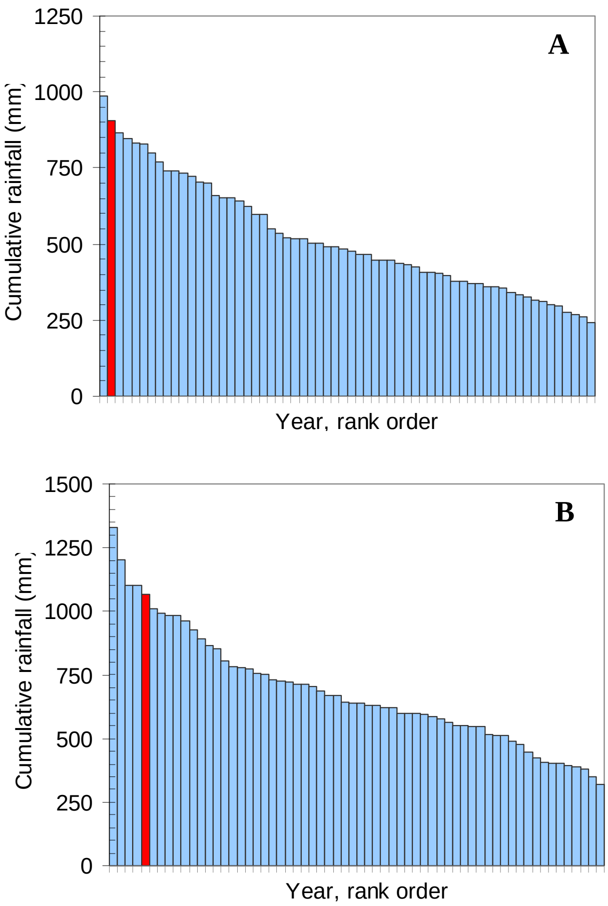

Fig. 5. Blue bars show cumulative rainfall for the Rijeka rain gauge, for the 3-month period from October to December (A), and for the 4-month period from September to December (B), in the period between 1948 and 2009. Bars arranged from high (left) to low (right) values of cumulative yearly rainfall. Red bars show cumulative rainfall for the same 3-month and 4-month periods in 1996.

However, analysis of the cumulative rainfall for the 3- month period from October to December (Fig. 5a) indicates that only once (in 2000, 986 mm) the cumulative rainfall for the 3-month period from October to December exceeded the cumulative value measured in 1996 (907 mm), and four times (in 1960, 1328 mm; in 1976, 1202 mm; in 1993 1103 mm; and in 2000, 1101,3 mm) the cumulative precipitation for the 4-month period from September to December (Fig. 5b) exceeded the rainfall measured in 1996 (1069 mm).

Analysis of the historical daily-rainfall record further indicates that high intensity rainfall is not uncommon in the Rijeka area. At the Rijeka rain gauge, in the 13-year period from 1993 to 2006, daily rainfall exceeded 50 mm 83 times, and 6 times 100 mm. In the 1996. eight daily rainfall exceeded 50 mm for 8 times, of these five were during October and November

5. Conclusions

Maximal annual flow for Rjecina spring is 7.76 m3/s and maximal flow ever recorded in Rjecina was 438 m3/s (100 g RP). Valici reservoir cannot accept maximal high waters. In the lower, downstream part, Rjecina flows through narrow canyon. Due to that there is a considerable flood risk for Rijeka city. The historic data showed strong correlations of flood/ rainfall events with mass movements (rockfalls and landslides), so, there is a need for estimation of flood and other related hazards in the area (particularly landslide and debris flow hazard).

A potential geohazard event could involve movement of slope deposits towards the channel of the Rjecina River and this could cause two secondary effects: damming of the Rjecina River leading to the formation of landslide-dammed lakes; as well as formation of a flooding wave due to destruction of the natural landslide dams, and consequent flooding of the lower central area of Rijeka city 4).

In torrential watercourses such as Rjecina, floods are not unusual. Large variations of discharge, short flood wave propagation time, high sediment transport and the narrow corridor available for evacuation of flood waves require a specific approach to flood control problems.

Flood protection founded on the conventional principles - regulation of the river channel and construction of protective facilities does not provide full and permanent protection from floods, and the application of the recent achievements in flood control is justified. One of such methods is the numerical modeling of flood wave propagation, which enables the water management professionals to examine various possible flood scenarios and varying of different parameters directly affecting the occurrence of floods, and to select the optimum solutions for the protection of the city of Rijeka. The city of Rijeka is located 5 km downstream of the Rjecina river and hence there is a considerable risk of flood should the river be temporarily dammed as a result of further mass movement.

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リエチナ川流域の洪水危険性に関するシナリオ考察–グロホボ地滑りの影響を評価して

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要 旨

リエカ市に河口をもつリエチナ川はクロアチアの典型的な海岸カルスト地域を流れ，急流な河道をもつ代表的な河川である。河道の流域中央部は渓谷の最も不安定な箇所で地滑り災害の危険性が高い。ここでの岩盤移動は主に炭酸塩岩とフリッシュ岩の接触によっておこる。この渓谷の両岸斜面では落石と地滑りの発生が記録されている。これらを考慮するとリエチナ川の河道が落石や地滑りにより閉塞され，洪水イベントが発生する可能性がある。強い降水や地震の発生などは落石や岩石滑りの引き金となり天然ダム崩壊などによる土石流発生の可能性がある。本論文では甚大な規模の斜面崩壊やそれに関る土石流が発生したシナリオおよびモデル構築に関する基本的なアプローチを示す。

キーワード：地滑り，土石流，フリッシュ岩，降雨イベント