Editors: Snježana Mihalić Arbanas and Željko Arbanas

Landslide and Flood

Hazard Assessment

ICL

ICL ABN ADRIATIC-BALKAN NETWORK

CROATIAN LANDSLIDE GROUP

Landslide and Flood Hazard Assessment

Snježana Mihalić Arbanas • Željko Arbanas
Editors

Landslide and Flood Hazard Assessment

Proceedings of the
1st Regional Symposium on Landslides
in the Adriatic-Balkan Region
with the
3rd Workshop of the Croatian-Japanese Project
'Risk Identification and Land-Use Planning
for Disaster Mitigation of
Landslides and Floods in Croatia'

Croatian Landslide Group
Faculty of Mining, Geology and Petroleum Engineering
of the University of Zagreb
Faculty of Civil Engineering of the University of Rijeka

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Foreword

Exposure of people, economic assets and social infrastructures to small and large-scale landslides caused disasters in the past and poses considerable risk to our society over the world. Even this year, a large-scale landslide triggered by heavy rainfalls claimed a toll of 2700 on May 2nd, 2014 in Badakhstan, Afganistan. On August 20th, 2014 in Hiroshima, Japan, a local and heavy rainfall (rainfall intensity for three hours was historically the largest in this area) triggered small and rapid landslides which killed 74 people in the urban area. Climate change intensifies the frequency and magnitude of heavy rainfall and triggers landslides in many countries. The Adriatic-Balkan region is in the landslide hot spot zone where both landslide triggering factors of rainfall and earthquakes are active, and slopes are steep due to tectonic movement.

The International Consortium on Landslides (ICL) was established in 2002. It is an international non-governmental and non-profit scientific organization promoting landslide research and capacity development for the benefit of society and the environment. ICL created the International Programme on Landslides (IPL) with regards to the 2006 Tokyo Action Plan which is jointly managed by the IPL Global Promotion Committee. The Members of IPL-GPC are all members of ICL and ICL-Supporting organizations (UNESCO, WMO, FAO, UNISDR, UNU, ICSU, WFEO and IUGS).

ICL applied for a SATREPS (Science and Technology Research Partnership for Sustainable Development) program funded by the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA) to implement a joint project between Croatia and Japan in 2008. The budget was approved and ICL has started a new IPL project "IPL-161 Risk identification and land-use planning for disaster mitigation of landslides and floods in Croatia" from 2009. This project is very successful in research, capacity development and social implementation. To develop this initiative in the Adriatic-Balkan region, the Adrian-Balkan Network of ICL (coordinator: Snježana Mihalić Arbanas; co-coordinators: Željko Arbanas and Biljana Abolmasov) was established in 2012 following the ICL Strategic plan 2012-2021. The 1st Regional Symposium on Landslides in the Adriatic-Balkan Region was organized by the Croatian Landslide Group (from the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb and Faculty of Civil Engineering of the University of Rijeka) on March 6th-9th, 2013 in Zagreb, Croatia. The book "Landslide and Flood Hazard Assessment" represents the proceedings of the 1st Regional Symposium on Landslides in the Adriatic-Balkan Region together with the 3rd Workshop of the Croatian-Japanese SATREPS Project "Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia".

I am deeply appreciative of all members of the organization committee of this successful regional symposium, the editors of this book, and JST and JICA for funding these initiatives. I would request all partners to support the further development of the Adriatic-Balkan Network of ICL and the successful organization of the 2nd Regional Symposium on Landslides in the Adriatic-Balkan Region to be held in Belgrade, Serbia on May 14th-16th, 2015.

Kyoji Sassa

Kyoji Sassa
Executive Director of
the International Consortium on Landslides
Kyoto, Japan

Preface

Throughout the Adriatic-Balkan Region, people continue to experience dangerous landslides and floods in response to unfavorable hydrometeorological events. These threats require the evaluation of potential hazards and the application of the appropriate countermeasures based on research. Landslide and flood research is an interdisciplinary field that primarily encompasses scientists from geomorphology, engineering geology, hydrology, hydrogeology, geotechnical and hydrotechnical engineering in collaboration with researchers from such fields as geodesy, geophysics, and many others.

This book contains most of the papers presented at the 1st Regional Symposium on Landslides in the Adriatic-Balkan Region entitled 'Landslide and Flood Hazard Assessment' with the 3rd Workshop of the Croatian-Japanese SATREPS FY2008 Project 'Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia'. The symposium was held in Zagreb, Croatia from March 6th to 9th, 2013. A wide range of landslide topics are presented in the Workshop and Symposium sessions that include landslide mapping, landslide investigation, landslide monitoring, landslide hazard and risk assessment, and landslide stabilization and remediation measures.

This collection of papers covers recent case histories, theoretical advances, laboratory and field-testing, and design methods beneficial to practitioners, researchers and other professionals. The proceedings reflect the ongoing response of researchers and practitioners from Bosnia and Herzegovina, Croatia, Japan, Macedonia, Romania, the Russian Federation, Serbia, Slovenia, Switzerland, the United Kingdom and Vietnam.

We are using this opportunity to express our gratitude to the Japan International Cooperation Agency (JICA), Japan Agency for Science and Technology (JST) and Ministry of Science, Education and Sports of the Republic of Croatia for financing the scientific joint-research bilateral Croatian-Japanese project 'Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia'. Regional scientific cooperation was initiated and developed through the Project Workshops held in Dubrovnik in 2010 and in Rijeka in 2011 and finally resulted in the organization of this Symposium. We would also like to extend our appreciation to the Symposium and Workshop Organizing Committee, the government of the City of Zagreb, as well as to Croatian-Japanese Project member institutions for supporting the organization of the Symposium.

We would like to thank all authors and participants for sharing their ideas and results in the area of landslide and flood research. We wish to acknowledge the help from all the reviewers in advising and refining the contributions.

Snježana Mihalić Arbanas

S. Mihalić A.

Željko Arbanas

3rd Workshop of the Croatian-Japanese Project
'Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia'

Project Workshop Institution:
International Consortium on Landslides (ICL)
University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
City of Zagreb, Emergency Management Office
University of Rijeka, Faculty of Civil Engineering
Niigata University, Research Institute for Natural Hazards and Disaster Recovery
Kyoto University, Disaster Prevention Research Institute (DPRI)
University of Split, Faculty of Civil Engineering, Architecture and Geodesy
University of Zagreb, Faculty of Agriculture
Croatian Geological Survey

Supported by:
Ministry of Science, Education and Sports, Republic of Croatia (MZOS)
Japan International Cooperation Agency (JICA)
Japan Science and Technology Agency (JST)

Contents

Workshop Sessions

Landslide Investigation and Monitoring

Landslide Mapping and Susceptibility Assessment

Flash Floods and Debris Flows

Symposium Sessions

Landslide Investigation, Modeling, Remediation and Monitoring

Landslide Hazard Mapping: Inventories, Susceptibility, Hazard and Risk

Flash Floods and Debris Flows

Hydrologic Data Analysis for the Grohovo Landslide Area

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Abstract This paper describes the hydrological analysis of measurement data obtained by measuring instruments that were installed on the Grohovo landslide and Valići accumulation. The hydrological analysis is performed on hydrologic data obtained from the meteorological station on the crown of Valići Dam, which is located immediately upstream of the Grohovo landslide. The meteorological station measures 35 hydrologic parameters; some of these parameters serve as inputs for numerical models of debris flow and mud flow propagation. The hydrological analysis of the Grohovo landslide requires the real-time estimation of storm water discharge and volume in the section of the drainage canal located in front of the gabion retaining wall, which is situated at the bottom of the Grohovo landslide. The data are obtained by Mini Diver instruments installed in the drainage canals, which measure variations in the surface water levels. This paper provides a comparison of 2011 and 2012 hydrologic data, as well as guidelines for future research on the Grohovo landslide area.

Keywords Grohovo landslide, hydrological analysis, meteorological station, Mini Diver instrument

Introduction

The Rječina River, whose composition derives from the Grohovo landslide, is the most important river on the Kvarner coast. Its length constitutes 18.7 km. The spring of the Rječina River is a karst spring that is located at the foot of the Gorski Kotar Mountains and drains water from the vast underground karst. The Valići Dam and the Valići accumulation, which are located in the central area of the river, are situated immediately downstream of the Grohovo landslide. The Rječina River has extremely torrential features with large flow oscillations, which have caused significant damage along the riverbed in the past. The average and maximum spring water discharge rates are 7.17 m^3/s and 60.1 m^3/s, respectively; however, the Rječina River is frequently dry (Žic et al. 2012). The average annual water discharge rate for the Grohovo station, which is located immediately downstream of the Valići dam, was 9.12 m^3/s prior to the construction of the accumulation. Currently, the average annual water discharge rate is 1.66 m^3/s (Rubinić and Sarić 2005). Recent research in the area of the Grohovo landslide indicates that the risk of sliding rock masses has not been eliminated. The area of the valley between the Valići accumulation and the Rječina River near the canyon entrance represents the area with the greatest risk of instability in the vicinity of Rijeka city (Vivoda et al. 2012). Potential consequences include backfilled river beds, the demolition of naturally forming dams and the propagation of water waves to the mouth of the Rječina River.

The Grohovo landslide is located on the northern slope of the Rječina river valley, north of Rijeka city. Although its most recent period of activity occurred in 1996, it is an active landslide. Multiple phenomena of slippage were registered at the end of the 19^{th} century in the area of the landslide, with disastrous consequences. The area in the vicinity of the landslide is relatively unstable (Vivoda et al. 2012). The rearrangements of the river beds due to slides of rock mass represent a significant risk of danger. The total size of the landslide is estimated at approximately 18 ha (300*600 m). Siliciclastic flysch or basic rocks are characterized by substantial lithological heterogeneity due to frequent vertical and lateral alternation of various lithological members, such as marls, siltstones, shales and fine-grained sandstones (Benac et al. 2005, Benac et al. 2006). Flysch rock mass exhibits weak permeability, which causes susceptibility to decomposition and erosion. The entire area is characterized by a network of small streams that erode slopes and significantly enhance the production of sediment in the Rječina basin.

The Croatian-Japanese bilateral scientific research project entitled "Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia" (Mihalić and Arbanas, 2013) monitors the area of the Grohovo landslide with respect to the behavior of landslide bodies, causes of and potential for sliding, hazard and risk assessments of potential surfaces, and the establishment of a monitoring and early warning system for new skating areas. In the hydrological studies, we continuously collect hydrologic data for the development of 2D and 3D numerical models to simulate the propagation of flash floods and debris flow during landslides or rockslides, in which large quantities of debris accumulate in the river bed.

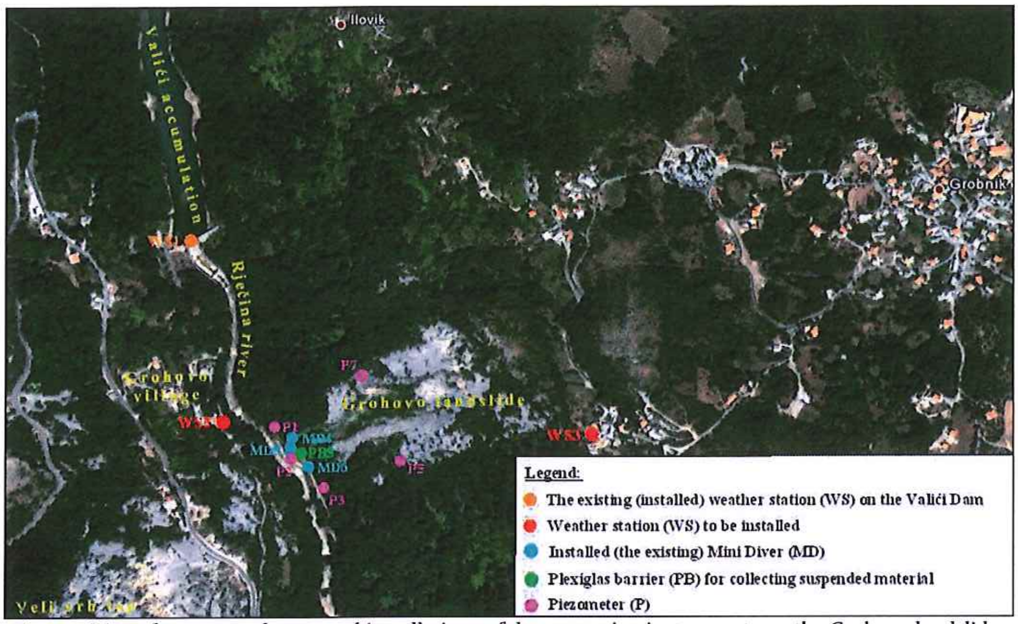

Figure 1 Map of current and proposed installations of the measuring instruments on the Grohovo landslide.

Installation of equipment on the Grohovo landslide

To monitor the Grohovo landslide, several measuring instruments were installed to measure hydrologic and hydraulic parameters. At the end of May 2011, the Vantage Pro2 weather station was installed in the middle of the crown of the Valići Dam (WS1, Fig. 1) near the Grohovo landslide (approximately 200 m from the foot of the Grohovo landslide). The weather station measured 35 hydrologic parameters. The time steps (increments) used for the collection of hydrologic data consist of 10-minute intervals. The Vantage Pro2 wireless weather station includes two components: the integrated sensor suite (ISS), which houses and manages the external sensor array, and the console, which provides the user interface, data display and calculations. The ISS and the Vantage Pro2 console communicate via an FCC-certified, licence-free, and frequency-hopping spread spectrum (FHSS) transmitter and receiver. The standard version of the ISS contains a rain collector, temperature sensor, humidity sensor and anemometer. In addition to the standard weather features, the ISS Plus also contains a pre-installed solar radiation sensor and a ultra-violet (UV) radiation sensor. The console displays and records the station's weather data, provides graph and alarm functions, and interfaces to a computer using optional WeatherLink software. The WeatherLink software and data logger connect the Vantage Pro2 weather station directly to a computer, which enables enhanced weather-monitoring capabilities, continuous and preserved data records, and powerful Internet features. The console of the meteorological station, which was installed 70 m from the weather station within the water-protection house, enables downloading of wireless data to the console via a USB cable. The data were collected beginning on June 13, 2011 and were updated every 16 days. To develop an efficient numerical model (Debris Flow Modelling) of the Grohovo landslide, the installation of two new Davis Vantage Pro2 weather stations and their associated equipment (WS2 and WS3 in Fig. 1) will ultimately be required.

We installed three Mini Diver instruments at the foot of the Grohovo landslide to measure the surface water and groundwater that are collected through the gabion retaining wall. Mini Diver instruments have a ceramic pressure sensor, temperature sensor, data recorder and battery, which are placed in a hermetically sealed stainless steel box. This box reduces the sensitivity of the Mini Diver instrument to moisture and electrical influences. The Mini-Diver instrument is equipped with a memory capacity of 24,000 measurements. The first Mini Diver instrument (MD4) is mounted at the end of the left drainage channel, the second (MD5) Mini Diver instrument is mounted at the end of the right-hand drainage channel, and the third Mini Diver instrument (MD6) is placed at the end of the channel that runs parallel to the gabion retaining wall (collects leachate behind the gabion retaining wall), as shown in Figure 2. Data collection using the Mini Diver instrument began on July 11, 2011. The time steps (increment) for the data collection are comprised of 1-minute intervals. Mini Diver instruments 4, 5 and 6 (MD4, MD5 and MD6) are placed in a drilled hole with a depth of 17 cm in the middle drainage channel of the storm water.

Five piezometers were installed in the area of the Grohovo landslide (P1, P2, P3, P5 and P7 in Fig. 1). Three piezometers were installed on the lower part of the landslide (at the landslide foot), and two piezometers were installed in the middle of the slide zone. The three lower piezometers (P1, P2 and P3) measure the

Figure 2 Positions of the Mini Diver instruments near the foot of the Grohovo landslide.

groundwater levels, whereas groundwater levels (recharge to the Rječina stream) are measured at the base of the upper piezometers (P5 and P7). Continuous monitoring of groundwater levels began in December 2011 for piezometer P1 and in February 2012 for piezometer P3. The hydrological analysis of fluctuations in groundwater levels in the vicinity of the Grohovo landslide was not discussed in this paper.

The required measurement and research equipment, numerical programs, and systems and equipment for the meteorological and hydrological observations were provided by the Japanese government as part of the Croatian-Japanese bilateral scientific research project (Mihalic and Arbanas 2012). The remaining research equipment was provided by the faculty of the Department of Civil Engineering at the University of Rijeka.

Data analysis for the Grohovo landslide

The research methods are based on hydrologic and hydraulic data that were collected from field measurements in the Grohovo landslide. The database contains real-time data collected with the installed measuring devices: weather station, Mini Diver and Baro Diver instruments, ombrographs, limnigraphs, satellite radar and an ADCP flow meter. The research methods include surface exploration, groundwater exploration (measurement of groundwater levels in the area of the Grohovo landslide), 2D and 3D numerical modelling, and GIS technology; all are dependent on the availability of data at the defined locations. Based on the hydrological and hydrogeological data, 2D and 3D numerical models of debris flow propagation were constructed. The following section includes graphical views and a brief analysis of the most important real-time hydrological parameters for 2011 and 2012, which can serve as parameter inputs for numerical models.

Figure 3 displays the variation in the outside air temperatures in the area near the Grohovo landslide. The maximum air temperature in August 2011 was 33.7 °C, whereas the minimum air temperature in December 2011 was -3.6 °C. The output humidity in 2011 ranged from 24% to nearly 100%. The mean air density on the Grohovo landslide in 2011 was approximately 1.17 kg/m^3. Minimum and maximum air density values were 1.123 kg/m^3 and 1.228 kg/m^3, respectively. The maximum dew point recorded for a given area was 22.3 °C.

Note that no hydrologic data were measured during the period of July 22 to the end of July, as shown in Figure 4, due to certain hydraulic repairs within the crown of the Valići Dam. The maximum and minimum

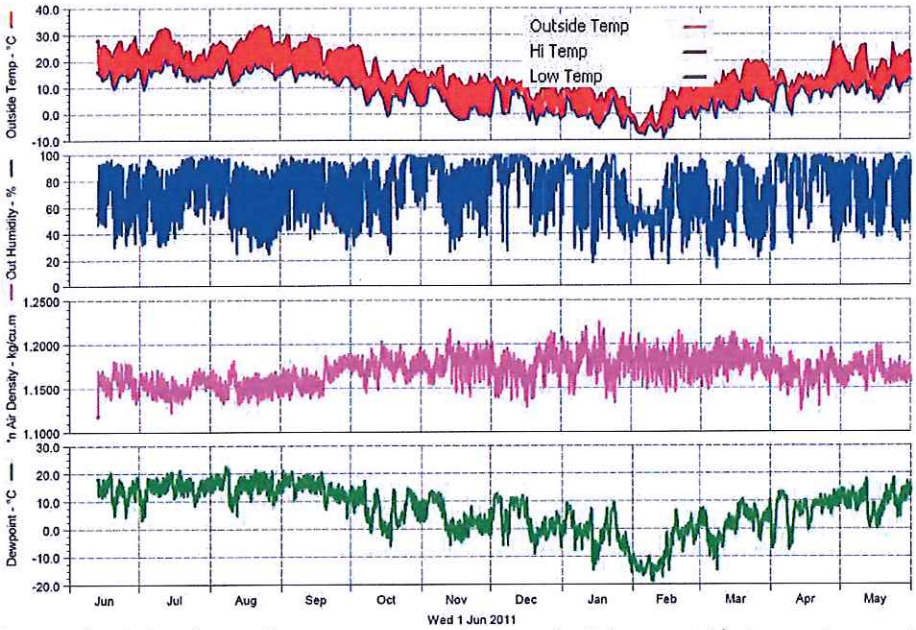

Figure 3 Graphical view of variations in outside temperature, maximum and minimum outside temperatures, outside humidity, air density values and dew point in real time in 2011, Weather station, Valići Dam.

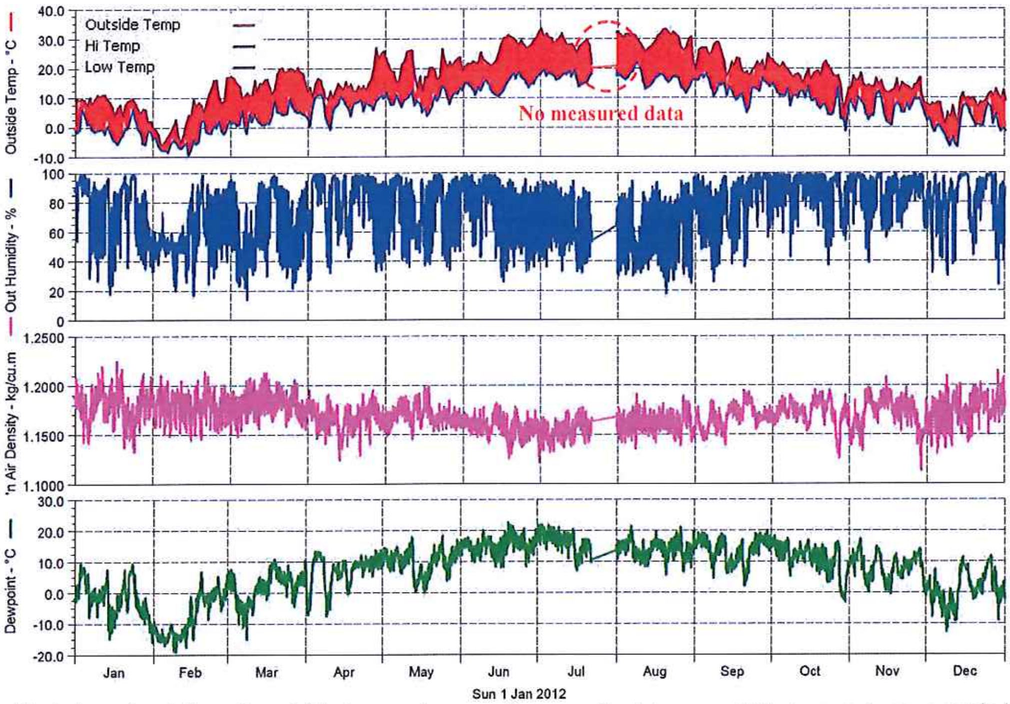

Figure 4 Graphical view of variations in outside temperature, maximum and minimum outside temperatures, outside humidity, air density and dew point in real time in 2012, Weather station, Valići Dam.

recorded outside air temperatures in 2012 were 32.3 °C (in June) and -9.3 °C (in February), respectively. The air humidity ranged 14-100%, whereas the minimum and maximum air densities were 1.112 kg/m^3 and 1.225 kg/m^3, respectively. The maximum dew point was slightly greater than 21 °C (in June and August), as shown in Figure 4.

Rain intensity is an important parameter for monitoring the occurrence of debris flow propagation, which is closely linked to the saturation of terrain materials and potential landslide triggering. Figure 5a displays the high variability of total monthly rainfall in 2011. The majority of the precipitation, 237 mm, fell during the month of October, whereas the lowest amount of rainfall, 5 mm, was recorded in August. 2012 was a slightly rainy year, in which the maximum monthly precipitation occurred in October (338.6 mm); March and July were the driest months of the year (1.4 mm and 0.4 mm, respectively). The minimum atmospheric pressure corresponded to the greatest rainfall intensities, whereas the maximum atmospheric pressure corresponded to predominantly dry periods (Figs 5a,b). Tables 1 and 2 list the monthly cumulative values for the variations in air temperature, precipitation and wind speed for 2011 and 2012 on the Valići accumulation. In 2011, the Grohovo landslide experienced a total of 672.6 mm of rainfall (from June through December), whereas the total rainfall experienced in 2012 was 1484.9 mm.

This paper provides an overview of the variations in maximum wind speed and evapotranspiration in the Grohovo landslide area for 2011 and 2012, as shown in Figures 6a and 6b. The maximum recorded wind speed in 2011 was 86.9 km/h (in July), whereas the mean value for the entire year was approximately 6.0 km/h. A maximum wind speed of 83.7 km/h was recorded in 2012 (in February), whereas the mean annual wind speed was 6.1 km/h. The north wind was the dominant wind direction in the Grohovo landslide area. Maximum values of evapotranspiration were significant for the period of May to the end of August. In 2011, the maximum monthly amount of evapotranspiration was 87.8 mm (in August), whereas the lowest amount of evapotranspiration was 12 mm (in December). In 2012, similar values were recorded, with a maximum evapotranspiration of 85.8 mm (in August) and a minimum evapotranspiration of 10 mm (in December).

The processing of hydraulic data for the Grohovo landslide area included the collection of hydrological data from the three Mini Diver instruments, which were placed inside the drainage canals to collect rainwater and seepage water from the area of the Grohovo landslide. Based on the measured water levels in the drainage channels in real time and based on the hydraulic geometric parameters (Tab. 3) measured for each cross section by the installed Mini Diver instrument, the maximum monthly flow velocity, water discharge and volume in the drainage channels were easily computed.

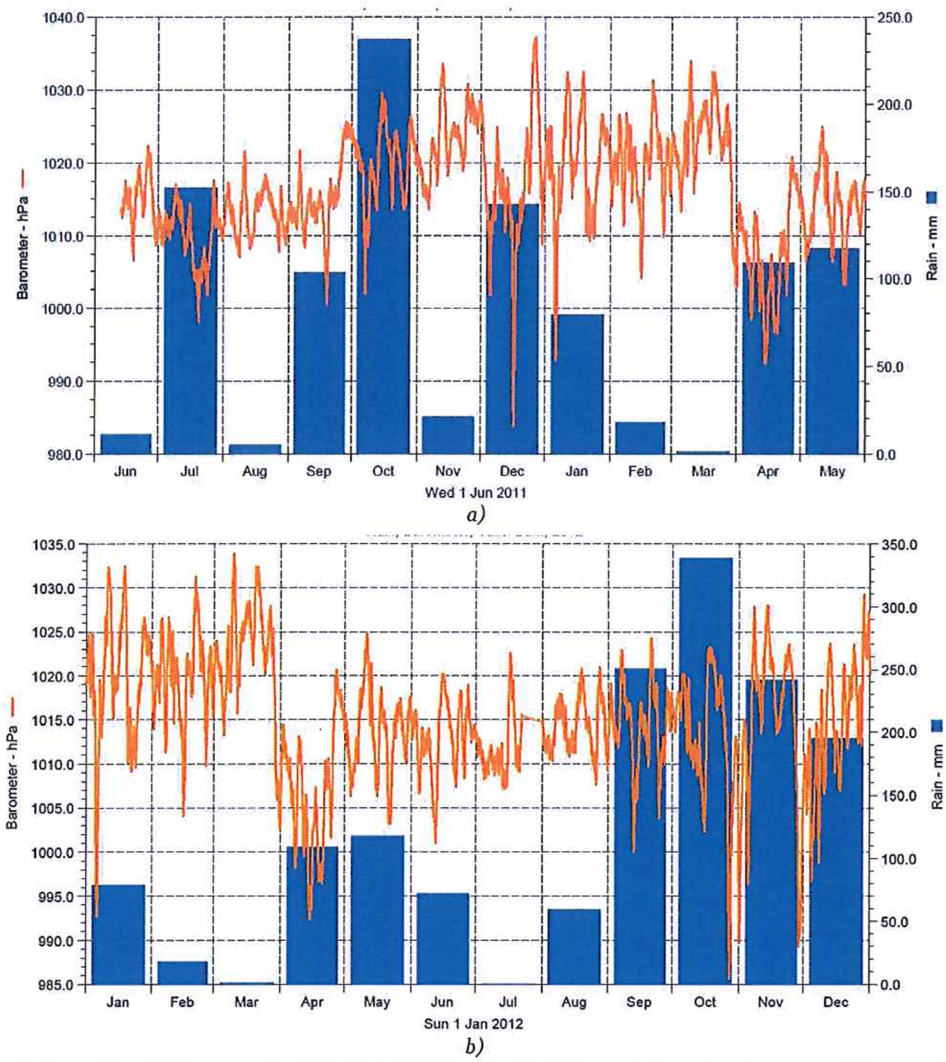

Figure 5 Graphical view of variations in atmospheric pressure and rainfall in real time in a) 2011 and b) 2012, Weather station, Valići Dam.

Table 1 2011 annual climatological summary, Weather station, Valići Dam.

TEMPERATURE (°C), HEAT BASE 18.3, COOL BASE 18.3															
YEAR	MONTH	MEAN MAX	MEAN MIN	MEAN	DEP. FROM NORM.	HEAD DEG DAYS	COOL DEG DAYS	HIGH	DATE	LOW	DATE	MAX>=32	MAX<=0	MIN<=0	MIN<=-18
11	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	6	25.6	13.9	19.7	0.0	21	45	29.4	29	9.5	20	0	0	0	0
11	7	25.5	15.2	20.2	0.0	32	90	32.7	12	9.2	3	4	0	0	0
11	8	28.4	15.7	21.6	0.0	19	122	33.8	23	10.8	11	7	0	0	0
11	9	25.8	14.3	19.4	0.0	38	71	30.1	3	10.6	25	0	0	0	0
11	10	16.8	6.5	11.0	0.0	234	9	26.2	2	-0.8	17	0	0	1	0
11	11	13.6	2.3	6.6	0.0	351	0	18.1	10	-2.4	19	0	0	12	0
11	12	10.3	2.3	6.0	0.0	381	0	13.7	8	-4.2	21	0	0	13	0
		20.6	**9.8**	**14.6**	**0.0**	**1076**	**338**	**33.8**	**AUG**	**-4.2**	**DEC**	**11**	**0**	**26**	**0**

Table 1 2011 annual climatological summary, Weather station, Valići Dam, continue.

PRECIPITATION (mm)										WIND SPEED (km/hr)					
YERR	MONTH	TOTAL	DEP. FROM NORM.	MAX. OBS DAY	DATE	DAYS OF RAIN OVER 0.2	2	20		YERR	MONTH	AVER.	HIGH	DATE	DOMIN. DIREC.
11	1	-	-	-	-	-	-	-		11	1	-	-	-	-
11	2	-	-	-	-	-	-	-		11	2	-	-	-	-
11	3	-	-	-	-	-	-	-		11	3	-	-	-	-
11	4	-	-	-	-	-	-	-		11	4	-	-	-	-
11	5	-	-	-	-	-	-	-		11	5	-	-	-	-
11	6	11.0	0.0	8.6	19	2	2	0		11	6	5.9	37.0	18	N
11	7	152.0	0.0	43.0	23	12	9	3		11	7	5.8	86.9	21	N
11	8	5.0	0.0	3.4	1	4	1	0		11	8	6.2	33.8	10	N
11	9	103.6	0.0	60.0	19	6	5	2		11	9	5.9	48.3	20	N
11	10	237.0	0.0	82.0	7	8	5	4		11	10	6.1	45.1	21	N
11	11	21.2	0.0	12.2	7	6	3	0		11	11	6.7	32.2	12	N
11	12	142.8	0.0	33.0	14	16	11	3		11	12	5.7	56.3	19	N
		672.6	**0.0**	**82.0**	**OCT**	**54**	**36**	**12**				**6.0**	**86.9**	**JUL**	**N**

Table 2 2012 annual climatological summary, Weather station, Valići Dam.

TEMPERATURE (°C), HEAT BASE 18.3, COOL BASE 18.3															
YEAR	MONTH	MEAN MAX	MEAN MIN	MEAN	DEP. FROM NORM.	HEAD DEG DAYS	COOL DEG DAYS	HIGH	DATE	LOW	DATE	MAX>=32	MAX<=0	MIN<=0	MIN<=-18
12	1	7.5	-0.9	2.8	0.0	481	0	11.2	11	-5.7	28	0	1	23	0
12	2	4.3	-3.9	-0.0	0.0	531	0	16.8	29	-9.3	14	0	10	25	0
12	3	15.7	3.5	9.5	0.0	274	1	20.1	28	-2.2	8	0	0	1	0
12	4	14.6	7.1	10.7	0.0	234	6	26.8	28	-0.8	10	0	0	1	0
12	5	20.2	9.3	14.5	0.0	138	20	26.4	24	3.9	18	0	0	0	0
12	6	25.5	14.3	19.5	0.0	39	77	31.2	19	10.3	15	0	0	0	0
12	7	28.9	17.2	23.0	0.0	4	107	33.3	2	13.8	17	2	0	0	0
12	8	29.7	16.3	22.9	0.0	14	158	33.2	20	11.6	28	4	0	0	0
12	9	22.6	12.9	17.2	0.0	71	37	28.8	9	4.9	21	0	0	0	0
12	10	17.8	8.8	12.6	0.0	181	4	22.8	1	-1.3	30	0	0	1	0
12	11	13.9	6.6	10.1	0.0	247	0	18.3	5	0.5	17	0	0	0	0
12	12	8.1	0.9	4.3	0.0	433	0	12.8	28	-6.7	13	0	0	12	0
		17.2	**7.5**	**12.0**	**0.0**	**2647**	**410**	**33.3**	**JUL**	**-9.3**	**FEB**	**6**	**11**	**63**	**0**

PRECIPITATION (mm)										WIND SPEED (km/hr)					
YERR	MONTH	TOTAL	DEP. FROM NORM.	MAX. OBS DAY	DATE	DAYS OF RAIN OVER 0.2	2	20		YERR	MONTH	AVER.	HIGH	DATE	DOMIN. DIREC.
12	1	79.4	0.0	53.6	3	8	4	1		12	1	6.0	38.6	30	N
12	2	18.0	0.0	12.6	20	3	2	0		12	2	8.9	83.7	7	N
12	3	1.2	0.0	0.8	18	3	0	0		12	3	6.7	48.3	10	N
12	4	109.0	0.0	30.0	11	19	11	1		12	4	5.2	53.2	1	N
12	5	117.8	0.0	47.0	7	13	8	1		12	5	6.0	64.4	14	N
12	6	72.0	0.0	29.4	12	11	5	2		12	6	5.4	37.0	13	N
12	7	0.4	0.0	0.4	15	1	0	0		12	7	6.7	54.7	22	N
12	8	59.4	0.0	34.8	31	4	2	2		12	8	6.7	53.1	26	N
12	9	251.0	0.0	113.8	19	15	7	2		12	9	5.3	66.0	14	N
12	10	338.6	0.0	105.6	15	24	11	4		12	10	5.6	57.9	27	N
12	11	242.1	0.0	54.6	1	20	11	5		12	11	5.3	64.4	5	N
12	12	196.0	0.0	67.4	15	16	10	3		12	12	5.3	67.6	8	N
		1484.9	**0.0**	**113.8**	**SEP**	**137**	**71**	**21**				**6.1**	**83.7**	**FEB**	**N**

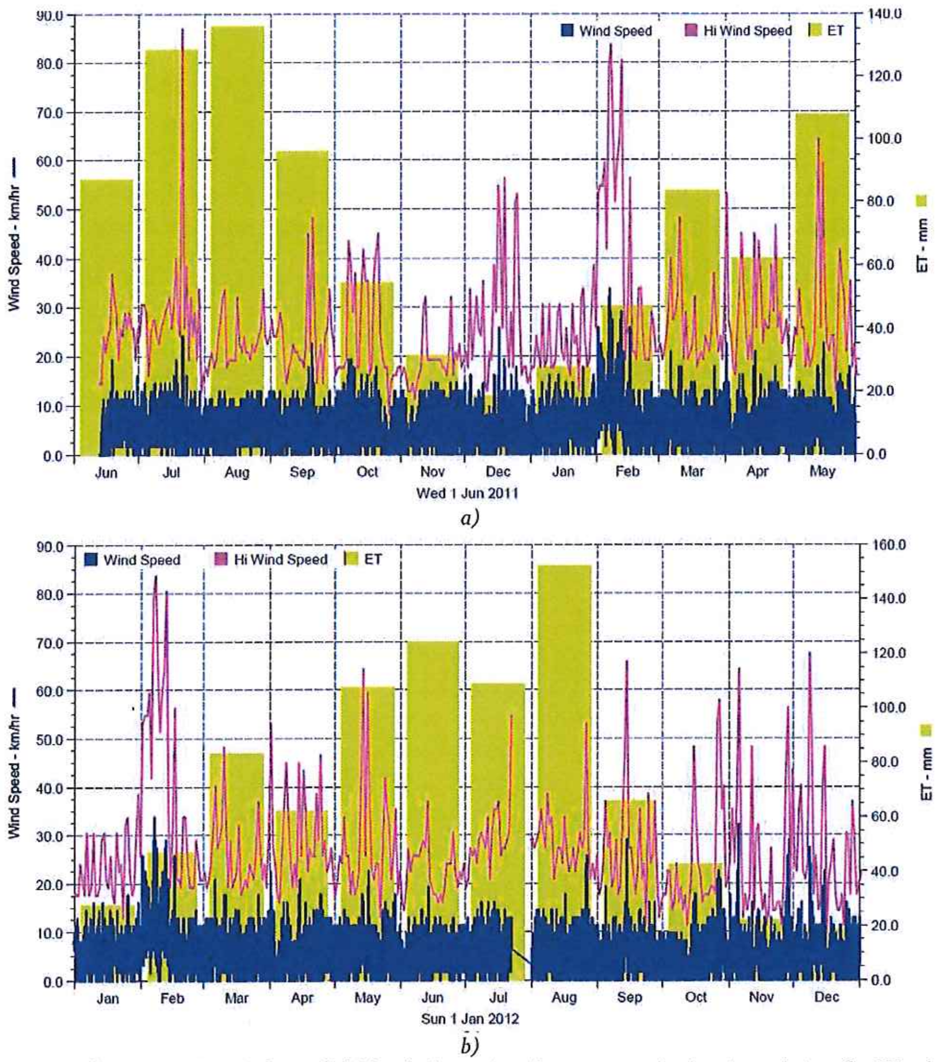

Figure 6 Graphical view of variations in wind speed, high wind speed and evapotranspiration in real time for Weather station, Valići Dam: a) 2011 and b) 2012 year.

Table 3 Geometric and hydraulic characteristics for the channel profile of the positions of the installed Mini Diver instruments, Grohovo landslide.

	MINI DIVER 1	MINI DIVER 2	MINI DIVER 3
Hole depth for Mini Diver instrument [m]	0.170	0.160	0.165
Channel slope [%o]	32.0	6.6	13.6
Slope of the left channel side [°]	30.58	37.88	41.33
Slope of the right channel slope [°]	25.25	47.95	29.18
Manning's roughness coefficient [$m^{-1/3}s$]	0.030	0.030	0.030
Time step [s]	60.00	60.00	60.00
Bottom channel width [m]	0.800	0.510	0.870

Figures 7 to 9 illustrate the variations in maximum monthly water levels, maximum monthly flow velocities in the channel and maximum monthly water discharges in the channel for the positions of Mini Diver instruments 1, 2 and 3 from July 2011 to December 2012. At the left-hand drainage channel, the maximum flow velocity was 3.34 m/s, as shown in Figure 7. These high speeds are common for a high channel slope of 32%. In August and September 2011, no water levels were recorded by the Mini Diver instruments; thus, the flow velocity, water discharge and volume of storm water were not measured. At the beginning of February 2012, freezing water was discovered in the drainage channels in the area of the Grohovo landslide due to a strong winter and low temperatures (-9.3 °C, 30 cm ice layer). During this period, the Mini Diver instruments incurred damaged to the ceramic membranes, which caused them to be unusable. As a result, new Mini Diver instruments were installed at the end of March. The maximum monthly water volumes in the left-hand drainage channel (position of Mini Diver 1) were the highest in November (14,055.03 m^3) and October (11,177.18 m^3) of 2011, as shown in Table 4.

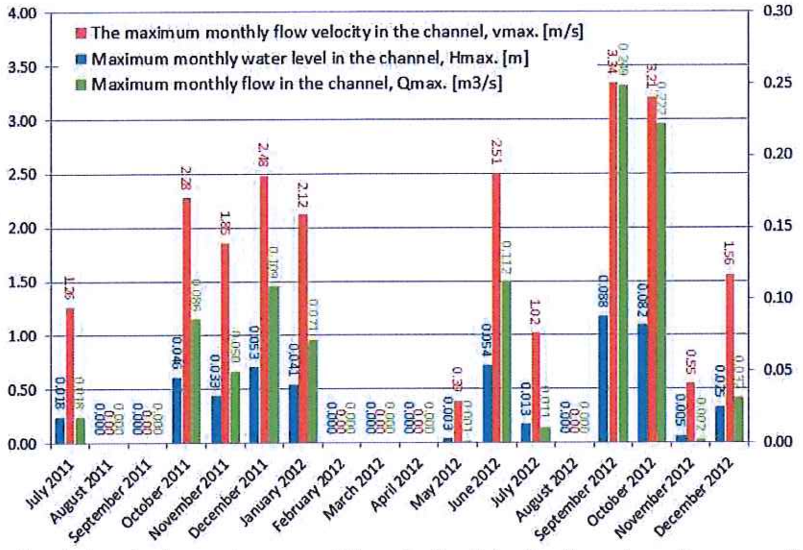

Figure 7 Graphical view of variations in the maximum monthly water levels in the channel, maximum monthly flow velocities in the channel and maximum monthly water discharges in the channel for the period of July 2011 to December 2012, Mini Diver instrument 1, Grohovo landslide.

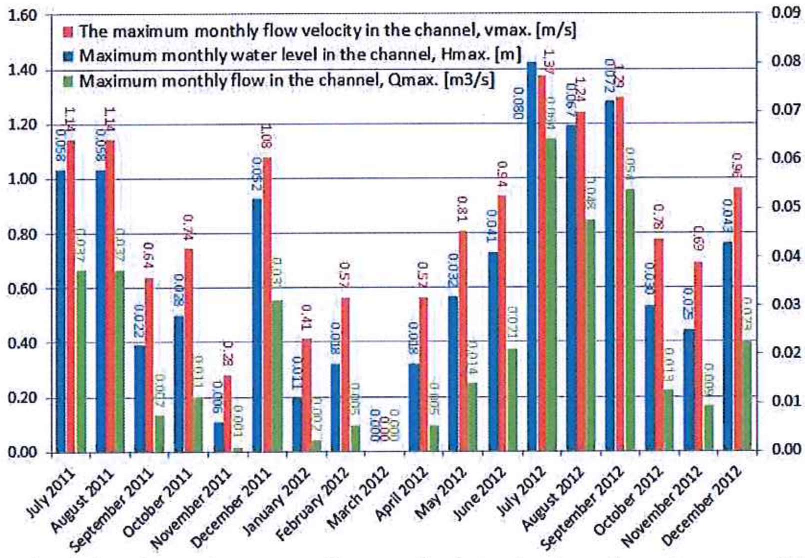

Figure 8 Graphical view of variations in maximum monthly water levels in the channel, maximum monthly flow velocities in the channel and maximum monthly water discharges in the channel for the period of July 2011 to December 2012, Mini Diver instrument 2, Grohovo landslide.

The flow velocity in the main drainage channel (position of Mini Diver instrument 2) consisted of 0.28 to 1.37 m/s, the maximum recorded water discharge was 0.053 m^3/s (Fig. 8), and the maximum recorded total monthly volume of water in July and December of 2012 were 13,987.64 m^3 and 7,278.55 m^3, respectively, as shown in Table 4. The minimum total monthly volume of water was 2.50 m^3 in November 2011.

The maximum total monthly water volumes for the right-hand drainage channel on the Grohovo landslide (position of Mini Diver instrument 3), which is located in front of the gabion retaining wall, were 20,859.77 and 13,329.5 m^3 in July 2011 and August 2011, respectively, as shown in Table 4. The maximum monthly water flow velocities for a given channel ranged from 0.12 to 1.80 m/s, the water levels ranged from 8 to 63 mm, and the maximum recorded water discharge was approximately 0.10 m^3/s (December 2011), as shown in Fig. 9.

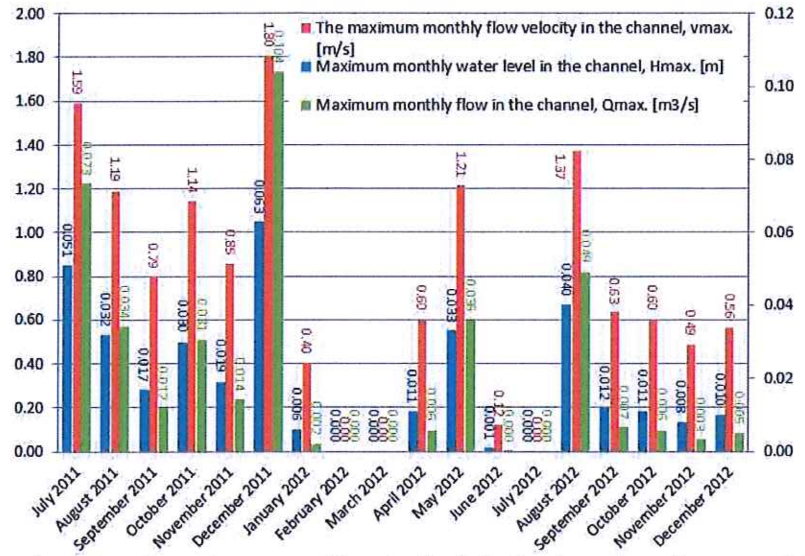

Figure 9 Graphical view of variations in maximum monthly water levels in the channel, maximum monthly flow velocities in the channel and maximum monthly water discharges in the channel for the period of July 2011 to December 2012, Mini Diver instrument 3, Grohovo landslide.

A review of total monthly storm water levels for individual drainage channels in the Grohovo landslide is provided in Table 4. Based on the hydraulic calculations of stormwater runoff for the drainage channels under the Grohovo landslide, the cumulative annual volume of storm water in 2011 and 2012 were calculated as 66,266.71 m^3 and 42,931.91 m^3, respectively. Although the hydraulic analysis for 2011 only included the last 6 months of the year (July to December), the total annual storm water volume was significantly higher compared with the entire 2012 year. Although the volume of water during the winter months was anticipated to be significant, the maximum monthly water volumes occurred in July and August.

Table 4 Total monthly water volumes for the period of July 2011 to December 2012. Mini Diver instruments 1, 2 and 3, Grohovo landslide.

Month	Monthly amount of water volume, [m^3],			Total monthly amount of water volume, [m^3],
	MINI DIVER 1	MINI DIVER 2	MINI DIVER 3	
	V_{month}, [m^3]	V_{month}, [m^3]	V_{month}, [m^3]	$V_{tot.month}$, [m^3]
July 2011	374.93	1256.32	20859.77	22491.02
August 2011	0.00	746.72	13329.50	14076.22
September 2011	0.00	247.09	370.23	617.32
October 2011	11177.18	212.65	1224.77	12614.61
November 2011	14055.03	2.50	1644.46	15701.99
December 2011	749.56	3.15	12.85	765.55
January 2012	1160.63	3.70	0.23	1164.56
February 2012	0.00	230.75	0.00	230.75
March 2012	0.00	0.00	0.00	0.00
April 2012	0.00	230.75	20.05	250.80
May 2012	0.07	4130.92	259.76	4390.76
June 2012	1095.73	884.69	0.01	1980.42
July 2012	53.07	13987.64	0.00	14040.71
August 2012	0.00	1080.49	291.99	1372.48
September 2012	1609.55	7123.87	6.66	8740.08
October 2012	1174.27	361.98	6.33	1542.58
November 2012	1.08	1848.77	13.16	1863.00
December 2012	57.43	7278.55	19.77	7355.75
			Sum (2011):	**66266.71**
			Sum (2012):	**42931.91**

Conclusion

One of the primary goals of the Croatian-Japanese bilateral project is to analyse the input and output parameters associated with the flood wave and landslides. The basic parameters are as follows: terrain morphology and conditions of surface and ground water, the intensity and duration of rainfall, cumulative rainfall, the frequency of rainfall prior to sliding, the impact of the seasons and climate changes, the slope stability (stability of cut slopes) and drainage conditions, density and type of vegetation cover, and seismicity areas. These parameters indicate the causes of sliding on inclines, which were comprised of flysch formation, and the occurrence of debris flow. Based on collected meteorological, hydrological and geological data from the Grohovo landslide, 2D and 3D numerical models of debris flow propagation downstream of the Rječina River were developed. The data results from the established meteorological and hydrological monitoring system indicate the efficiency and adequacy of the established system and reveal any necessary modifications of the system. Continuous monitoring and data collection, as well as future simulation models will enable the establishment of an early warning system for the dangers of flooding.

Acknowledgements

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