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RIVER ENGINEERING MEASURES IN AN ALPINE RIVER AFTER A MAJOR DEBRIS FLOW EVENT

FLUSSBAULICHE MASSNAHMEN IN EINEM ALPINEN FLUSS NACH GROSSEM MURGANGEREIGNISS

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ABSTRACT

On November 17, 2000, a wet debris flow with a volume of more than 1 million m^3 formed from the Stože Landslide and flowed along the Predelica channel to hit the village of Log pod Mangartom (NW Slovenia). It killed 7 people, and devastated the Koritnica River valley, a tributary of the Soča River. Nearly 700,000 m^3 of debris material were deposited in this narrow alpine valley, locally with a thickness up to 10 m. Immediately after the catastrophe, first river engineering measures were done under the civil defence command. Later on, an outline scheme for river engineering measures was adopted as a part of the final remediation of the area. As a basis for this scheme, the results of a hydrologic analysis, granulometric analysis of debris deposits, and preliminary evaluation of cross-sectional sediment transport capacities were used. A river bed width of 8 m for the Koritnica River (I ~ 2.2 %, $Q_{100} > 250$ m^3/s) and 3 m for the Predelica Torrent (I ~ 4.6 %, $Q_{100} = 77$ m^3/s) was chosen. The form of the planned final river cross sections was also determined using results of the mathematical modelling of possible debris flows of the same magnitude as in November 2000. Until late 2003, nearly 240,000 m^3 of the debris flow deposits have already been eroded by river erosion.

Key words: debris flows, landslides, natural disasters, river engineering, torrent control

ZUSAMMENFASSUNG

Am 17. November 2000, hat sich ein nasses Murgang mit einem Volumen von mehr als 1 Million m^3 aus der Stože Rutschung gebildet, und ist entlang des Predelica Gerinnes geflossen um in das Dorf Log pod Mangartom (NW Slowenien) einzuschlagen. Es gab 7 Opfer, und das Murgang verwüstete das Tal des Koritnica Flusses, das selber ein Nebenfluss des Soča Flusses ist. Nahe 700,000 m^3 von Murgangmaterial wurden in diesem engen alpinen Tal abgelagert, lokal auch bis zu 10 Metern hoch. Gleich nach der Katastrophe wurden die ersten flussbaulichen Massnahmen unter der Zivilschutzkommando ausgeführt. Später wurde ein Rahmenplan für die flussbaulichen Massnahmen als ein Teil der endgültigen Sanierung des Gebietes entwickelt. Als die Grundlage für diesen Plan wurden die Resulate einer

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hydrologischen Analyse, einer Analyse der Kornzusammensetzung der Murgangablagerungen, und einer Vorstudie über die Profil- Sedimenttransportkapazität. Als Flussbettbreite wurde 8 Meter für den Koritnica Fluss (I ~ 2.2 %, Q_{100} > 250 m^3/s) und 3 m für das Predelica Wildbach (I ~ 4.6 %, Q_{100} = 77 m^3/s) gewählt. Das Form von den endgültigen Fluss-querprofilen wurden auch an Hand der Resultate der mathematischen Modelierungen von möglichen Murgängen mit einer gleichen Ausmass wie im November 2000 bestimmt. Gegen Ende 2003, wurden bereits fast 240,000 m^3 von Murgangablagerungen durch Flusserosion erodiert.

Key words: Flussbau, Murgänge, Naturkatastrophen, Rutschungen, Wildbachverbauung

INTRODUCTION

The Soča River valley, situated along the Slovenian–Italian border, is well known in the Eastern Alps to be hit on average with more than 40 thunderstorms a year. Through history, local residents have accommodated to such a wet climate, and only few buildings are within flooded areas. The extent of the Stože landslide and the catastrophic consequences produced by a following debris flow in November 2000, which devastated the Koritnica valley near the Slovenian-Italian border, were quite different from what local people have experienced in the last decades and therefore rather a surprise. This paper is about the carried out river engineering measures related to remediation of the devastated area. More on meteorological and hydrological causes of the Stože landslide, is given elsewhere (Mikoš et al., 2004).

CATASTROPHIC CONSEQUENCES AND THE REMEDIATION PLAN

The first landslide slipped on the Stože slope (Fig. 1) on 25 ha around 1 p.m. on November 15, 2000, after a long wet period of intensive rainfalls. The Stože slope, covered with beech forest with some pine trees, failed between 1200 m and 1500 m, and slipped masses of nearly 1 million m^3 turned to a dry debris flow. It destroyed the Mangart alpine road and a concrete intake structure for a small HPP, and stopped in the Mangart Creek's torrential channel with the 15 % longitudinal slope.

Just after midnight on November 17, 2000, 35 hours after the first event, the deposited masses of the first dry debris flow started to flow again. More than 1 million m^3 of wet material (by rainfall and also infiltrating running waters) flowed as a wet debris flow through a narrow channel of the Predelica Torrent for 4 km to the village of Log pod Mangartom (Fig. 2) and further downstream in the Koritnica River valley. The maximum flow velocity of the debris flow was estimated to be well over 10 m/s in the steep and narrow channel of the Predelica Torrent, and between 3 and 5 m/s in the more open valley of the Koritnica River. These estimated values were confirmed using one 1-D (PLAZ1D) and two different 2-D mathematical models for debris flows (commercial Flo-2d, PCFLOW2D) (Četina & Krzyk, 2003). The debris flow reached the village in a few minutes, killed 7 people in their homes, destroyed 6 and severely damaged 23 residential or farm buildings as well as devastated nearly 15 ha of agricultural land, mainly pastures. The total direct economic losses were estimated at over € 10 million. Debris flow was mainly depositing its masses along the flowpath and only locally eroding very narrow sections. Debris deposits were locally deep as much as 10 meters, and were so wet, that large machinery was unable to work on it for nearly two weeks. Finer fractions of debris masses were immediately transported downstream in suspension together with wooden debris, and deposited along the Soča River, so that local floodings were caused.

Fig. 1: A view towards the Stože slope after the event (on November 29, 2000).
Abb. 1: Blick an das Stože Hang nach dem Ereignis (am 29. November 2000).

Fig. 2: Debris flow deposits in Log pod Mangartom (photo: November 28, 2000). The Predelica Torrent comes from the right and flows to the Koritnica River, coming from the left.
Abb. 2: Ablagerungen des Murganges in Log pod Mangartom (Foto: 28. November 2000).

First rehabilitation measures were successfully done early in 2001. All communications were renewed; two destroyed bridges on the regional road have been replaced by a temporary construction (steel bridge). The destroyed concrete intake structure for two small HPPs have been rebuilt, and the Mangart alpine road has been partially repaired. A feasibility study, which was approved by the Slovenian Government and Parliament, foresaw that the rehabilitation works would have been finished within the next 3 years and estimated the cost at around € 35 million. So far, five destroyed residential buildings have been replaced, and several more will be built in future on new and safe locations as determined by hazard zone planning. The hazard zones were determined by using the before mentioned two-dimensional mathematical models for debris flow and different possible scenarios for further landsliding in the area.

HYDROLOGICAL ANALYSIS OF THE EVENT

The Koritnica River catchment covers an area of 87 km^2. Permeable karst and alluvial formations are prevalent in this mountainous catchment, the only formation of low permeability is located in the sub-catchment where the Stože landslide occurred.

The rainfall distribution and hydrological conditions in the catchment are not well known due to lack of gauging stations. Long term water balance in the Koritnica catchment gives 2853 mm of annual precipitation, 489 mm of evapotranspiration, and 2601 mm of runoff. There is an obvious discrepancy of 237 mm between the annual runoff and vertical water balance, so it is supposed that the rainfall is underestimated. There is only one rainfall station in the catchment, situated in the village of Log pod Mangartom (650 m) and nearly 90 % of the area is higher than the station itself with Mangart (2679 m) as the highest peak. The rainfall station in Bovec (485 m), situated further downstream in the Soča River valley, shows on average 20 % higher annual rainfall depths than those measured in Log pod Mangartom. Unfortunately, the Stože slope itself as well as the whole Predelica Torrent catchment are surrounded by high mountains, and not visible by both operating meteorological radars in this part of the Alps (Fossalone in Italy, and Lisca in Slovenia).

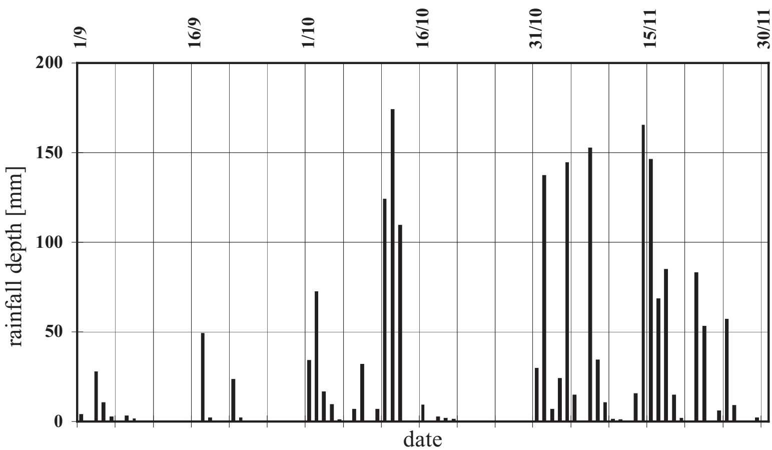

Fig. 3: Measured rainfall depths in the rainfall station in Log pod Mangartom in autumn 2000.
Abb. 3: Gemessene Regenmengen in Regenmessstation Log pod Mangartom im Herbst 2000.

Rainfall season in autumn 2000 started in the beginning of October with a following period of intensive rainfalls until the end of November (Fig. 3). It was quite warm, so that up to 1800 m no snow accumulation was registered. Rainfall depths for a period of one and two months exceeded the 50-year return period (Tab. 1). The measured rainfall depths in Log pod Mangartom was unexpectedly higher in this period when compared to the rainfall station in Bovec. Intensive shorter periods of rainfall: 407.4 mm (October 11-13), 380.2 mm (November 14-16), and daily rainfall depths: 174 mm (October 12) and 165.3 mm (November 14, a day before the first landslide) were not extreme for this area (Fig. 3, Tab. 1).

Tab. 1: Measured rainfall depths at rainfall gauging station in Log pod Mangartom compared with statistical values given for different recurrence intervals for this gauging station (reference period 1961–1990).
Tab. 1: Gemessene Regenmengen in Log pod Mangartom im Vergleich mit berechneten Werten angegeben für verschiedene Wiederkehrperioden für diese Regenmessstation (Referenzperiode von 1961 bis 1990).

	recurrence interval [years]						measured	
duration	2	5	10	25	50	100	[mm]	period
1 day	170	226	263	309	344	378	174.0	12.10.2000
7 days	359	453	515	594	652	710	481.6	11.11.–17.11.2000
1 month	496	684	808	966	1082	1198	1042.7	18.10.–17.11.2000
2 months	756	1018	1192	1411	1574	1735	1666.4	18.9.–17.11.2000

A hydrological model of the Koritnica catchment was developed using WMS and validated using discharge data from a Koritnica River gauging station, where a series of flood waves were registered in autumn 2000. Base flow increased throughout November 2000, and so did the runoff coefficients: surface runoff coefficient rose from 0.17 to 0.37, and total runoff coefficient rose from 0.28 to 0.62.

A few months after the event, field measurements of spring waters in the Stože landslide area were done using natural isotopes of $\delta^{18}O$ and tritium. The isotope content from the samples indicated that water had accumulated in the slope for a few years (Mikoš et al., 2004).

SEDIMENTOLOGICAL STUDY

After the devastating Stože landslide and the following debris flow event on November 17, 2000, the granulometric composition of debris flow deposits in the Koritnica River valley was analysed (Mikoš et al., 2002a). Altogether 8 volumetric and 4 Wolman samples were taken in the area. Their grain size distribution is given in Fig. 4, the grain parameters are given in Tab. 2, and separately in Tab. 3 for computed probes using Anastasi's procedure (1984).

Tab. 2: Grain parameters for sampled debris flow deposits in the area of the village of Log pod Mangartom.
Tab. 2: Kornparameter von Proben von Murgangsmaterial in Log pod Mangartom.

Parameter	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8
d_{16} [mm]	0.06	1.82	1.23	0.67	5.3	4.0	1.4	2.8
d_{50} [mm]	10.21	9.16	10.76	10.23	23.5	21.9	11.5	20.1
d_{84} [mm]	45.58	21.17	54.06	31.65	50.9	53.4	44.2	48.5
d_{90} [mm]	65.21	24.65	101.14	43.31	57.0	60.4	54.6	54.9
varianca [–]	28.10	3.41	6.62	6.90	3.1	3.6	5.7	4.1
d_m [mm]	22.08	11.45	25.46	15.93	26.3	26.4	18.8	23.4

Tab. 3: Mean arithmetic diameter in mm of sampled probes on June 26, 2001, and computed probes of debris flow deposits, using Anastasi's procedure (1984), in the area of the village of Log pod Mangartom.
Tab. 3: Mittlere Korndurchmesser in mm von am 26. Juni 2001 entnommenen und nach dem Verfahren von Anastasi (1984) zusammengelegten Proben von Murgangsmaterial in Log pod Mangartom.

Sample	Sampled probes	Computed probes		
number	Volumetric sample	Rigid conversion	Fuller curve	Flexible conversion
5	26.3	53.6	50.7	49.1
6	26.4	41.4	42.4	35.1
7	18.8	43.7	50.4	50.1
8	23.4	48.8	50.4	42.6

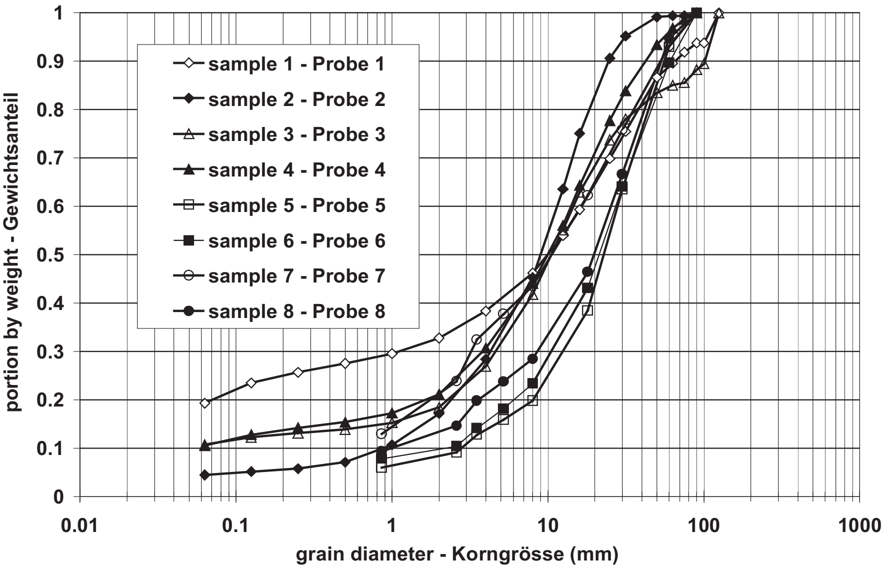

Fig. 4: Grain size distribution of debris flow deposits in Log pod Mangartom – samples from 1 to 4 were taken on November, 21 and 22, 2000, samples from 5 to 8 were taken on June 26, 2001.
Abb. 4: Kornverteilungen von Murgangablagerungen in Log pod Mangartom – Proben von 1 bis 4 wurden am 21. und 22. November 2000, Proben von 5 bis 8 aber am 26. Juni 2001 entnommen.

As a part of the sediment budget analysis of the Koritnica River basin, computations of sediment transport capacity in the river reach in the village of Log pod Mangartom, SW Slovenia, were performed. A flood wave with a 2-year return period and a duration of 133 hours was chosen. The peak flood discharge was 34 m^3/s on the Koritnica River, and 13 m^3/s on Predelica Torrent, its right-hand side tributary in Log pod Mangartom. The calculation was based on characteristic bed slopes of the two streams in this area. The results are shown in Tab. 4 as a function of bed width of both streams, and mean sediment size, respectively. The computed optimal riverbed width giving the maximum sediment transport capacity in a cross section was strongly related to the mean sediment size. Maximum profile sediment transport capacity was achieved only for mean sediment size less than 20 mm and for the riverbed width less than 10 m for the Koritnica River, and less than 6 m for the Predelica Torrent.
The routing of several flood waves using the 1D mathematical sedimentological and hydraulic model to show morphological changes of the channel of the Koritnica River (Mikoš et al., 2002b) was computed. For the peak discharges of the chosen flood waves for the Predelica 12 m^3/s for all 3 waves, and for the Koritnica 18 m^3/s for the first and the third wave and 26 m^3/s

for the second wave were taken, respectively. Despite intensive sediment supply from the Predelica (4500 m^3), the sediment input was balanced by the sediment output. The model also predicted local erosion of up to 1 m of the Koritnica River bed in the section of the confluence with the Predelica Torrent after 3 consecutive chosen flood waves passed.

Tab. 4: Results of a comparative computation of profile sediment transport capacities (m^3/year) for three sediment mean grain sizes d_m and for two riverbed slopes I. The riverbed width of the Predelica Torrent is 6 m and of the Koritnica River is 8 m, respectively. The cross sections are of a trapezoidical form with bank slopes 1 : 2.
Tab. 4: Die Resultate der Vergleichsberechnungen von Profil-Sedimenttransportkapazitäten (m^3/Jahr) für drei mittleren Korndurchmesser des Geschiebes d_m und für zwei Längsgefälle I. Die Flussbettbreite ist für Predelica 6 m und für Koritnica 8 m. Die Querprofile sind trapezoidisch mit Böschungsneigungen 1 : 2.

Reach of the Predelica Torrent in Log				**Reach of the Koritnica River in Log**			
Average hydrological year – 1959				Average hydrological year – 1959			
I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm	I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm
4.0 %	276,541	139,867	65,505	2.7 %	454,752	231,427	111,247
4.28 %	345,793	178,382	87,599	2.9 %	566,795	298,481	149,050
Dry hydrological year – 1981				Dry hydrological year – 1981			
I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm	I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm
4.0 %	84,843	29,309	10,326	2.7 %	149,131	51,594	18,779
4.28 %	114,255	39,969	15,109	2.9 %	198,305	72,357	27,354
Wet hydrological year – 1960				Wet hydrological year – 1960			
I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm	I	d_m = 30 mm	d_m = 40 mm	d_m = 50 mm
4.0 %	597,167	355,426	186,201	2.7 %	946,560	576,951	310,037
4.28 %	713,402	442,143	242,403	2.9 %	1,130,332	718,635	403,182

RIVER ENGINEERING WORKS

All inhabitants of Log pod Mangartom were evacuated immediately after the event. During unfavourable meteorological conditions there was a latent debris flow hazard due to the unstable masses in the landslide area. The village of Log pod Mangartom was also subjected to a high flood hazard because of the filled river channels with around 700,000 m^3 of debris flow material. Due to the devastated surfaces along the debris flow path and deposited debris flow material (approximately 400,000 m^3) in the Mangart Creek and the Predelica Torrent upstream of the village (between the landslide area and the village), the hyperconcentrated sediment laden flows in the rainfall season were yet another hazard for the village (in late spring due to snow melting and in late autumn). When trying to organize the immediate relief action and the return of inhabitants the National Civil Defence Quarters decided in November 2000 to remove the debris flow deposits in the area, mainly by stimulating natural erosion and sedimentation processes. The approach was adequate in considering the fact that the devastated area lies within the Triglav National Park. Additionaly to this decision, and as a first relief action, in winter 2000–2001 60,000 m^3 was excavated from a narrow gorge of the Predelica immediately upstream of the village and transported to a dumping site downstream of the village. The main excavation in order to form new channels in the debris flow deposits was done in spring 2001. Altogether, 85,000 m^3 was excavated, 15,000 m^3 of which was put to the dumping site. The rest was rearranged within the cross sections in order to form a main channel being large enough to convey a 100-year flood.

Since the maximum volume of the available dumping sites in this narrow alpine valley was limited to approximately 100,000 m^3, out of which 75,000 m^3 were already used in spring 2001, later on natural fluvial erosion processes (incision, bank erosion) were given priority over further mechanical excavations, partially also due to financial reasons. As the main river engineering measure temporary river channels for the Predelica and the Koritnica were conceptually chosen in order to satisfy the following criteria:

- Flood safety of the village;
- Sediment transport capacity higher than sediment inflow from the landslide area in order to prevent sedimentation of these sediments in the area;
- Activation of channel erosion along both channels to stimulate eroding of debris flow deposits, also during medium flows.

When forming a main channel to convey a 100-year flood the whole available potential in the area was used (no ground sill or similar structures were built). The channel width was chosen to be of less than 50 % of the normal channel width prior to the event. In 2001, the channel bottom of the Predelica was excavated to 3 m in width, and that of the Koritnica to 6 m at a longitudinal slope of 0.026 and 8 m at a slope of 0.022. The planned normal channel bed width (to be reached after the remediation will be completed) of the Predelica at a slope of 0.046 was 6 m, and that of the Koritnica River at a slope of 0.026 was 16 m. Temporary channels were formed with ungrouping of excavated debris flow deposits within the cross sections without any substantial transport along the channels. The surface of the ungrouped deposits was inclined towards the main channel (Fig. 5).

Fig. 5: A view towards the Koritnica River channel in Log pod Mangartom immediately after the debris flow event in November 2000 and after the completion of the first river engineering works in July 2001.
Abb. 5: Blick in das Koritnica Gerinne in Log pod Mangartom sofort nach dem Murgang im November 2000 und nach der Fertigstellung von der ersten flussbaulichen Massnahmen in Juli 2001.

After completion of these measures in 2001, high flows caused the expected moderate erosion in the channels. The incision of channels was prevailing accompanied by moderate bank erosion of relatively dense and therefore stable debris flow deposits. In the period from November 2000 to summer 2002, 76,000 m^3 were eroded from the channels to downstream sections of the Koritnica River. In October and November 2002 some heavy rainfall occurred in the area, producing flood waves as shown in Fig. 6. Their return period was not higher than that of 5 years. In these two months in 2002 another 140.000 m^3 were removed out of the area by river erosion. The evolution of two less representative cross sections of the Koritnica River is shown in Fig. 7. In autumn of 2002 and in autumn of 2003 additional formings of the channels were done. The main aim of these efforts was to keep the dynamic characteristics of the channels and to limit bank erosion.

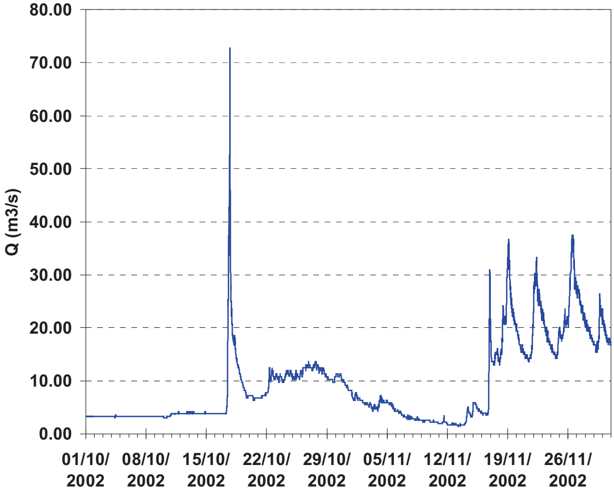

Fig. 6: Flood waves in October and November 2002, measured at the water level recorder in Kal-Koritnica.
Abb. 6: Hochwasserwellen im Oktober und November 2002, gemessen am Limnigraph Kal-Koritnica.

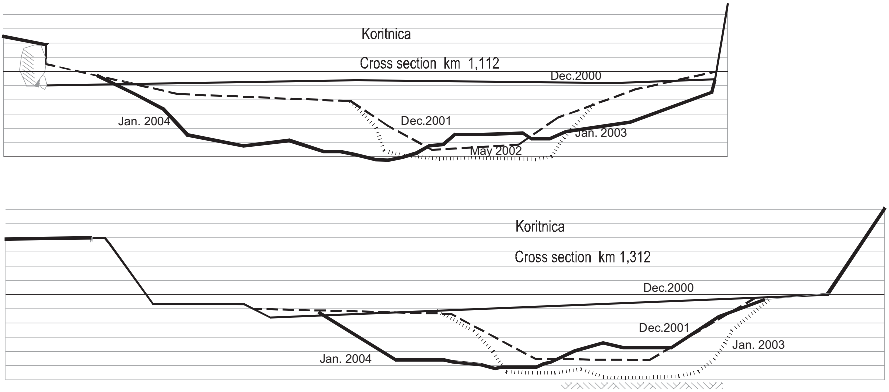

Fig. 7: The evolution of two cross sections of the Koritnica River after the debris flow event in November 2000. Vertical step is 1 m.
Abb. 7: Die Evolution von zwei Querprofile des Koritnica Flusses nach dem Murgang im November 2000. Der vertikale Schritt ist 1 m.

By March 2003, the channel incision stopped. During storms in August and early September 2003, even some sedimentation occurred with a simultaneous noticeable widening of the cross section. The channel bed of the Predelica Torrent in Log pod Mangartom rose by approximately 2 m due to the sediment inflow of several 10,000 m^3 of gravels (more than its average annual sediment yield). The bankfull width of the main channel changed from 15 m to up to 30 m. The channel of the Koritnica River rose by 1 m and widened by only several metres. The incision stopped due to widening of the main channel and because of intense erosion of debris flow deposits in the channels of the Mangart Creek and Predelica Torrent. Due to a change in the bed slope, this material settles in the lower reach of the Predelica

Torrent, flowing here on its alluvial fan, upstream of the confluence with the Koritnica River. It was transported further downstream during the following less sediment laden flows. In total, between March and September 2003, some 22,000 m^3, and during floods in autumn 2003 70,000 m^3 more were eroded, rising the total volume of naturally eroded debris flow deposits by January 2004 after the debris flow event in November 2000 to nearly 310,000 m^3.

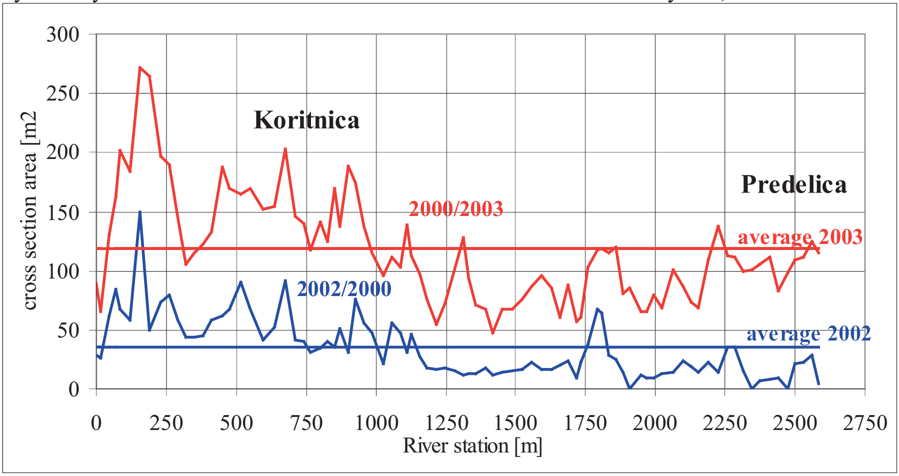

Fig. 8: Measured changes of the cross section areas of the Predelica Torrent and the Koritnica River in the area of Log pod Mangartom after the debris flow event in November 2000.

Abb. 8: Gemessene Differenzen in der Querprofilfläche des Predelica Baches und des Koritnica Flusses im Gebiet Log pod Mangartom nach dem Murgangereignis in November 2000.

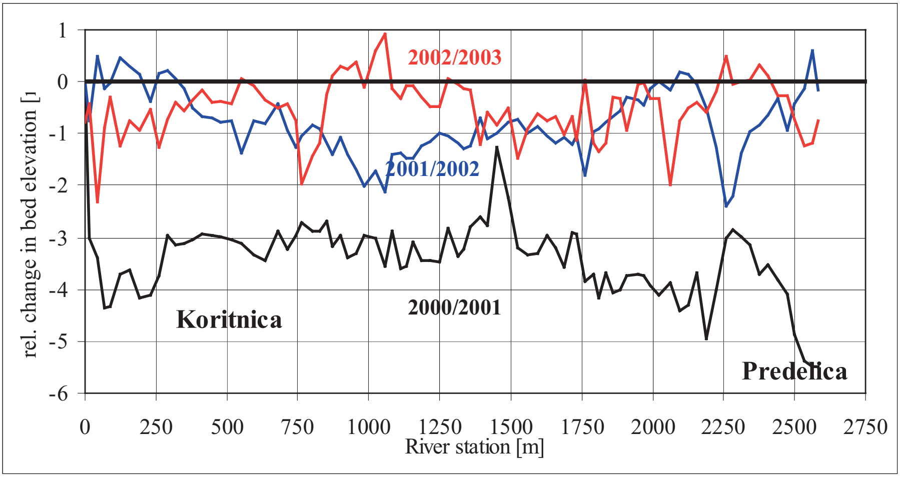

Fig. 9: Measured changes of the riverbed elevations of the Predelica Torrent and the Koritnica River in the area of Log pod Mangartom after the debris flow event in November 2000.

Abb. 9: Gemessene Differenzen in der Flussbetthöhen des Predelica Baches und des Koritnica Flusses im Gebiet Log pod Mangartom nach dem Murgangereignis in November 2000.

The evolution of river cross sections and their longitudinal profiles after the debris flow event in November 2000 is given in Figs. 8, 9 and 10. The river station 2,285 denotes the confluence of both rivers. Up to now, in some parts of the reach of the Koritnica River the initial elevation of the river bed prior to the event was achieved or even exceeded. The differences between 2001 and 2000 are mainly due to mechanical excavation works, afterwards mainly due to natural processes of river erosion.

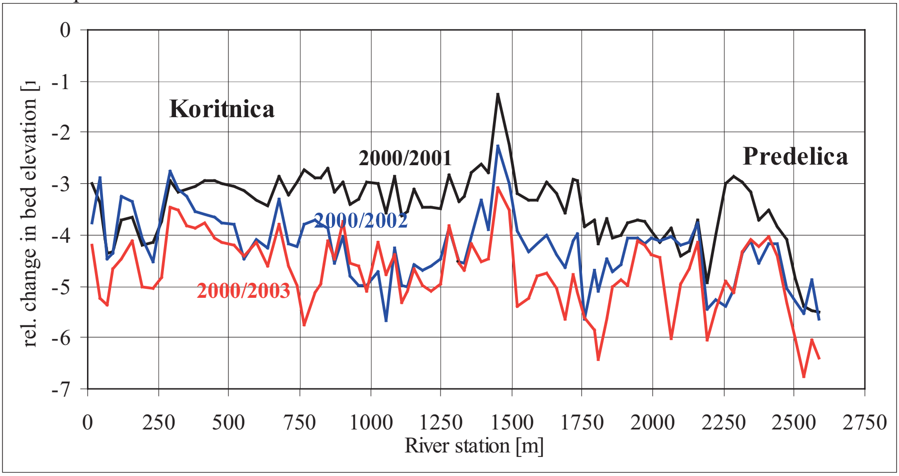

Fig. 10: Measured changes of the riverbed elevations of the Predelica Torrent and the Koritnica River in the area of Log pod Mangartom after the debris flow event in November 2000.
Abb. 10: Gemessene Differenzen in der Flussbetthöhen des Predelica Baches und des Koritnica Flusses im Gebiet Log pod Mangartom nach dem Murgangereignis in November 2000.

Altogether, from around 700,000 m^3 of debris flow deposits 100,000 m^3 of fines were transported out of the area immediately after the event in November 2000, 310,000 m^3 were eroded by the end of 2003, nearly 100,000 m^3 were excavated and put to higher elevation within the cross sections, and 75,000 m^3 were excavated and put to the dumping sites in the area. Natural processes of river erosion are still very active. Sand and gravel is eroded as bed load, and mud or silt as suspended load. During a flood event coarser fractions are transported for only a few kilometres, and further downstream of the village of Log pod Mangartom regular profilings of cross sections are needed to compensate for sedimentation in these reaches. High suspended load concentrations during high flows cause siltation problems in the downstream parts of the Soča River, e.g. in a chain of three reservoirs and hydro power plants.

CONCLUSIONS

In the area of Log pod Mangartom, the proposed and built river engineering measures generally fulfilled the expectations. To some extent, the processes of sediment delivery from the Predelica Torrent and as a consequence also erosion processes in the formed channels are more intense as initially expected. Furthermore, conditions in the devastated area, especially upstream of the village of Log pod Mangartom are still very unstable. That is why the final corrective river engineering measures in the valley still have to wait. As a most needed structure, a 10 m high debris flow breaker is planned to be built in the Predelica at the entrance to the village in order to stop the potential future debris flows with different consistency (dry and wet debris flows) and of volumes up to several 100,000 m^3. Its role will also be to act as a sediment retention basin in order to control the expected high sediment laden flows from the landslide area. The inflowing sediment should be retained upstream of the village in order to allow high flows to further erode debris flow deposits downstream to the Soča River, as observed in 2003. This high sediment input to the Soča River will compensate the observed decrease of its sediment transport rates in the last years, and will be under circumstances compensated by the temporal sediment dredging downstream of the confluence with the Koritnica River. The debris flow deposits in Log pod Mangartom are hardly to be used for any purposes apart from dumping them to selected dumping sites due to high portion of silt fraction. Once this material is fluvially reworked, fines are swept as a suspended load, and the coarse particles, still angular because of being transported in a mass movement event, will abrade to more round ones after 10 to 20 km of fluvial transport. Then, such material will be of interest for construction purposes, and a concession for sediment dredging will be successfully realised.

This case study has shown that after a major debris flow event river engineering measures must combine fast mechanical excavations of debris deposits in order to form rather narrow channels which will stimulate natural sediment transport processes. In the first phase, incision prevails, which later turns to lateral erosion. Such processes were in the case of the Stože debris flow deposits successfully stimulated by choosing channel widths of less than 50 % of the normal channel width. The final form of the Predelica and the Koritnica channels was optimised using the results of mathematical modelling of possible new debris flows from the Stože slope (Četina & Krzyk, 2003).

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