Technical Note

Standard Countermeasures Studies for Debris Flow Disasters in Brazil

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The GIDES Project, supported by JICA, is proceeding in Brazil in order to mitigate sediment disasters. A manual for the debris flow countermeasures has been drawn up as part of the Project goals. The manual is based on the Japanese guidelines for basic planning of countermeasures against debris flow and woody debris, however, adjustments were proposed due to typical natural and social conditions in Brazil. Some equations and coefficients were modified based on Brazilian field conditions. In addition, a flow chart was proposed in order to help engineers selecting debris flow suitable countermeasures. The manual methodology has been applied in two pilot project sites, regarding Brazilian areas affected by past sediment disasters : (1) The 2011 Região Serrana do Rio de Janeiro Disaster, and (2) the Santa Catarina state disaster occurred in 2008. This paper presents a summary of the Brazilian Manual for countermeasures planning against debris flow and introduces its methodology, showing two cases in which the manual guidelines were applied.

Key words: debris flow, countermeasures, sabo dams

1. INTRODUCTION

In August 2013, the Brazilian Cooperation Agency (ABC) and Japanese International Cooperation Agency (JICA) signed a development agreement for the Strengthening National Strategy on Integrated Management of Disaster Risk (GIDES). The main objective is to formulate strategies to improve alert systems and risk evaluation methods used in Brazil by incorporating them in the urban expansion policy.

These strategies include technical activities such as, knowledge exchanging among technical experts from Brazil and Japan, field surveys, several meetings and scientific and technological researches. All these activities were conducted to produce technical manuals such as the Debris Flow countermeasure manual that is outlined in this paper.

The present paper focuses on debris flow countermeasures as proposed in the specific manual following prevention-reconstruction strategy by reducing risks and also increasing the safety of disaster-affected areas. Furthermore, this paper presents two

study cases, in Nova Friburgo and Blumenau cities, at Rio de Janeiro and Santa Catarina states, respectively, with the purpose of verifying and improve the proposed methodology.

2. BRAZILIAN MANUAL FOR COUNTERMEASURES AGAINST DEBRIS FLOW

2.1 Debris flow countermeasures in Brazil

Large debris flow disasters in Brazil are considerably less frequent than other mass movements events. However, part of the low rates of debris flow occurrences in Brazilian records is due to misinterpretations of observed mass movements by local authorities . Therefore , countermeasures implemented to attend such types of disasters in Brazil are quite rare. The President Bernardes Refinery case [Kanji *et al.*, 2008], in Cubatão, São Paulo, is one of the most reported debris flow countermeasures case in the country.

This debris flow event took place on February 6,

1994, on the hill slopes of the Serra do Cubatão and damaged several facilities of the Cubatão refinery with a total loss amount reported of about US \$ 40 million [Kanji *et al.*, 2008]. Given the significative damages and losses, the refinery owner implemented an effective protection plan to prevent similar occurrences in the affected area with an estimated cost of US \$ 12 million.

In the Cubatão case, the debris flow peak flow rate was obtained by Takahashi [1991] equation, and a multidisciplinary working group was formed to study the problem, discuss solutions and propose the design criteria for the required countermeasures. This resulted in a set of countermeasures to control the debris flow peak and the accumulation of the transported solids based on control works following Japanese and Austrian experiences [Cruz *et al.*, 2004]. Although this remarkable case has brought extensive contributions in compiling and structuring international knowledge on debris flow to the Brazilian context, the adopted approach and the proposed actions were developed to a specific case and didn't aim to propose a general guideline for debris flow countermeasures.

In fact, there is a lack of information and national guidelines for debris flow countermeasures in Brazil. In this way, one of the greatest contributions of GIDES program is the issuing of the Brazilian Manual for countermeasures against debris flow based on the extensive Japanese expertise in the management and control of debris flow by structural countermeasures.

2.2 Features of debris flow in Brazil

Prior to the development of the Brazilian Debris Flow Countermeasure Manual, past debris flow disasters of 14 cases were surveyed and analyzed in Brazil in order to clarify their features compared to the ones observed in Japan. Consequently, it was found that the features of debris flow in both countries were generally similar.

The survey indicated that debris flow originated in the riverbed as well as in the mountain slope and contained driftwood regardless of the country. **Table 1** shows the change of debris flow behavior by riverbed gradient in both countries. **Figure 1** shows the relation between the debris flow runoff volume and the drainage basin area considering occurrences in Japan, recent events in the Região Serrana do Rio de Janeiro (mountain region of Rio de Janeiro) and Cubatão. These findings indicate similarities between the features of debris flow in Brazil and Japan and support the applicability of the Japanese guidelines to the Brazilian context except for a few points. The exceptional points are the rainfall analysis, the breast height coefficient in the driftwood production estimation, and the estimation of the debris flow peak

Table 1 Debris Flow behavior along riverbed gradient

Sediment Movement Form	Riverbed Gradient (°)	
	Survey in Brazil	Japanese Guideline
Occurrence Area	15-33	> 15
Flow Area	5-30	10-20
Deposition Area	2-10	2-15
End of Deposition	0.23-5	0.23-5

Fig. 1 Debris Flow Runoff Volume in Brazil and Japan

rate, which have been established reflecting the characteristics of Brazil. These aspects are explained in the following sections.

2.3 Brazilian manual overview

The Brazilian Manual for countermeasures against debris flow is structured in five chapters. The first chapter gives an introduction about the manual context, describing the objectives and the limitations regarding the application of the methodology. The second chapter concerns the countermeasures plan, focusing on its development. Chapter 3 contains several requirements for the countermeasure plan, including the methodology applied to estimate the planned debris flow volume and planned debris flow peak flow rate. Chapter 4 presents an approach to the definition of the most suitable countermeasure for each case. Chapter 5 deals with debris flow countermeasures indicated after each disaster phase, and chapter 6 addresses issues related to the use and occupation of areas where debris flow countermeasures were built.

The manual is aimed to be used by the government's expert technicians of Brazilian municipalities and also technicians from the business sector in charge of preparing debris flow countermeasures proposals.

3. PROPOSED METHODOLOGY

The proposed methodology is based on the Japanese guidelines for basic planning of countermeasures against debris flow and woody debris with some adjustments and adaptations that were performed by the GIDES team considering the Brazilian features. This section presents a brief description of the methodology approach adopted in the Brazilian Manual.

3.1 Planned reference point and debris flow movement zones

The planned reference point is defined as the point in which the quantity of sediment to be addressed should be determined [MLIT, 2007]. The countermeasures in a studied area will be defined accordingly to the volume of sediment evaluated in the planned reference point. Depending on the site characteristics, additional or supplementary reference points could be established. The planned reference point should be located upstream from the protected area. In case of additional reference planned points, it is recommended their establishment at locations where the sediment transport characteristics changes or at convergence points of tributaries. **Figure 2** presents a general overview of potential locations for the planned reference point and supplementary reference points in a hypothetical watershed.

To better address the reference and supplementary points location it is essential a general overview of the debris flow behavior along the torrent bed. MLIT [2007] presented a classification for the sediment

Fig. 2 Potential locations for the planned reference point and supplementary reference points in a hypothetical watershed

movement characteristics or forms according to zones or areas that are related to the torrent-bed gradient. Reaches with bed slopes higher than 15° are considered occurrence areas where the sediment material is generated. Bed slopes between 10° and 20° are considered flow areas where the sediment mass is basically moving through the main channel. Reaches with bed slopes between 2° and 10° are considered deposition areas in which the sediment material initiates its deposition. Finally, torrent beds with less than 2° are characterized by the spread of the sediment. As was discussed in the previous section and has been shown in **Table 1**, both Brazil and Japan present similar features regarding the relationship between the sediment movement form and the torrent bed slope. Having said that, the Brazilian manual maintained the same classification adopted by the Japanese guidelines. **Figure 3** presents the described forms of sediment movements according to specific zones as a function of the torrent bed gradient. Note that the zones ranges can overlap each other.

Considering the sediment movement zones, usually the planned reference point is positioned at the bottom end of the flow area and upstream from the protected area. However, in situations where it is not possible to build the countermeasure structure at the end of the flow area, the planned reference point could be shifted downstream to the deposition area, and an additional planned reference point(s) should be set above that location.

3.2 Quantity of debris to be addressed

For the sake of the terminology, in the Brazilian Manual, the term debris was employed for the material composed of sediment and driftwood. The term sediment was used to refer to any mineral particle, including blocks of rock that can be transported in the debris flow.

In this way, the quantity of debris do be addressed

Fig. 3 Potential locations for the planned reference point and supplementary reference points in a hypothetical watershed (adapted from MLIT, 2007)

in the countermeasure plan is composed of the planned sediment runoff volume and the planned driftwood runoff volume. The planned sediment runoff volume shall be determined based on topographical maps and records of past debris flow events. Field survey is recommended not only to improve the assessment of the study area but also to collect complementary field data to corroborate with the sediment and driftwood volume estimates as will be presented in the following sections.

The planned sediment runoff volume should be the smaller of two values: the movable potential sediment volume in the drainage basin and the transportable sediment volume in the drainage basin. As indicated in the Japanese guidelines, it is recommended a minimum of 1,000 m³ sediment runoff volume in case of the planned sediment runoff volume computation results in lower values than this reference. **Figure 4** presents a diagram with the debris flow volumes that should be addressed in the countermeasure plan.

3.2.1 Movable potential sediment volume

The movable potential sediment volume is theoretically that maximum sediment volume that can be generated and converted in debris flow in the worst-case scenario with no runoff constraints. This volume is computed as the sum of the movable sediment in the stream channels (1st order valley or higher) and the collapsible sediment located in basin's upstream top (0 order valley), as Eq. (1 a).

The boundary between 0 and 1st order valleys is defined based on topography where the depth of a concave contour line is smaller than the width, as shown in **Fig. 5**.

Fig. 4 Schematic diagram indicating the debris flow volume that should be addressed in a countermeasure plan

Fig. 5 Topography of the 0 th valley

Along the first or higher order valleys, movable sediment volume is estimated by the product of the tributaries lengths and estimated average cross-sectional area of movable sediment bed deposited in the stream, as in Eq. (1 b). The erosion area is estimated according to field surveys.

In 0 order valleys, collapsible sediment is estimated precisely by specific geological surveys or, in cases where it is not feasible, the use of the Eq. (1 c) is recommended.

$$V_{dy1} = V_{dy11} + V_{dy12} \quad (1 a)$$

$$V_{dy11} = \sum A_{dy11} L_{dy11} \quad (1 b)$$

$$V_{dy12} = \sum A_{dy12} L_{dy12} \quad (1 c)$$

where V_{dy1} is the movable potential sediment volume (m³), V_{dy11} is the movable sediment volume in tributaries (m³) (>1st valleys), V_{dy12} is the collapsible sediment volume in 0 order valleys (m³), A_{dy11} is the cross-section area of erodible sediment in tributaries (m²), A_{dy12} is the cross-section area of erodible sediment in 0 order valleys (m²), L_{dy11} is the length of the tributaries (m) and L_{dy12} is the length of 0 order valleys (m). **Figure 6** shows a sketch with the indication of the lengths for 0 order and non-0 order valleys.

3.2.2 Transportable sediment volume

The transportable sediment volume consists of the sediment volume that can be transported by the runoff associated with a specific rainfall event. This sediment volume is estimated based on an extreme precipitation event associated with a given return period based on specific risk studies. If these studies are unavailable it is recommended to adopt at least 100 years return period, according to other existing design recommendations from the Brazilian Federal Government.

The transportable sediment volume is computed by the expression presented in Eq. (2) as follows.

Fig. 6 Identification of the lengths of 0 and non-0 order valley orders

$$V_{dy2} = \frac{P_p \times A}{(1 - K_v)} \left(\frac{C_d}{1 - C_d} \right) K_{r2} \quad (2)$$

In which, V_{dy2} is the transportable sediment volume (m^3), P_p is the daily precipitation (mm) associated with a return period event, K_{r2} is a runoff correction factor ranging between 0.1 and 0.5 (determined by the chart presented in **Fig. 7**), A is the drainage basin area (km^2), C_d is the volumetric density of sediments in the debris flow (determined by Eq. 3) and K_v is the soil void ratio (assumed to be about 0.4 in the absence of further investigations).

It is recommended that the daily precipitation P_p follows the usual guidelines for drainage projects in Brazil based on statistical analysis of rainfall time series records with the following basic steps [Naghetini and Pinto, 2007] :

- prefer the use of annual rainfall time series ;
- analyze the time series in respect of homogeneity, correlation, and representability ;
- assume one (or more) theoretical probability distribution, estimating their correspondent parameters and checking their adherence to the time series record ;
- identify and try to correct some irregularities by repeating some of the steps above ;
- select the most appropriated distribution.

The volumetric density of sediments in the debris flow is determined by Eq. (3), proposed by Takahashi [2009].

$$C_d = \frac{\rho \tan \theta}{(\sigma - \rho)(\tan \phi - \tan \theta)} \quad (3)$$

Where : ρ is water density (approx.. $1,200 \text{ kg/m}^3$), σ is the density of gravel (approx.. 2600 kg/m^3), ϕ is the internal friction angle of sediment deposited on a torrent-bed (approx. 30° to 40° . In the absence of further information, 35° can be adopted) and θ is torrent bed slope gradient (in°).

The runoff correction factor K_{r2} is obtained as a function of the basin drainage area according to the chart presented in **Fig. 7** based on Japanese studies [MLIT, 2007]. In the absence of specific studies, it is suggested adopting that same relation. However, future investigations should be developed to verify that relationship to the Brazilian conditions.

3.2.3 Planned driftwood runoff volume

The planned driftwood runoff volume is obtained by the product of the driftwood volume production and the driftwood runoff rate.

Due to lack of specific studies on this subject in Brazil, it was assumed valid the driftwood runoff rate

Fig. 7 Runoff correction factor (K_{r2}) as function of Basin Drainage Area (A).

between 0.8 and 0.9, suggested by Ishikawa *et al.* [2003] when doesn't exist any debris flow/driftwood countermeasure structures.

The driftwood volume production (V_{wy}) is estimated by the following equation.

$$V_{wy} = \frac{B_d L_{dy13}}{A_s} \sum V_{wy2} \quad (4)$$

Where : B_d is the average width of the erodible cross-section in the valleys, L_{dy13} is the total length of valleys ($L_{dy11} + L_{dy12}$)(check **Fig. 6**), A_s is a sample surveyed area and V_{wy2} is the estimated tree wood volume in the surveyed area.

It is suggested the use of sample square areas of $10 \text{ m} \times 10 \text{ m}$ (i.e. A_s equal to 100 m^2), but other sample areas could be adopted since there are no established standards for this parameter in Brazilian forest inventories.

The evaluation of tree wood volumes in Brazil is frequently done by volumetric equations such as shown by Soares *et al.* [2009]. Such equations usually depend on two variables : the tree height (H_w) and the breast height diameter (D_w).

When these equations are not available for the investigated area, the use of the form factor method (or breast height coefficient) is indicated due to its simple formulation. In this case, the Eq. (5) should be used to compute the wood volume (V_{wy2}) in the surveyed area.

$$V_{wy2} = \frac{\pi D_w^2}{4} H_w K_d \quad (5)$$

Where : K_d is the breast height coefficient.

Based on the tree wood volume equations suggested by Soares *et al.* [2009], plots for the breast height coefficients as a function of the tree height (**Fig. 8**) for 5 native Brazilian species were generated. The presented plots considered only five species from a total of 10 species studied in Soares *et al.* [2009]. The curves for the other five species didn't result in good fit and were discarded. It is believed that the irregular stalks shapes of these species jeopardized the fit.

Future studies can be conducted to develop relationships between the breast height coefficient and the tree height for other Brazilian species.

3.3 Planned debris flow peak flow rate

The planned debris flow peak flow rate is the maximum value of the debris flow rate that passes through the planned reference point. This parameter is important to the design of the countermeasures structures. Two methods are presented in the Brazilian manual for evaluating the debris flow peak flow rate (Q_{sp}):

(a) Method 1: based on empirical relationships between the debris flow peak flow rate and the debris flow total income volume (ΣV);

(b) Method 2: based on the relationship between the debris flow peak flow rate and the water discharge peak flow rate (Q_p).

Empirical studies conducted by *Mizuyama and Uehara* [1984] in Yakedake, Sakurajima, Japan indicated a linear correlation between the debris flow peak flow rate (m^3/s) and the total volume of debris flow runoff (m^3) of about 0.1% and 0.01% for the first methodology. *Kanji et al.* [2008] investigated the empirical correlation presented in Method 1 to debris flows events occurred in 1994 and 1996 in the Pedras stream (Cubatão, SP). They considered flood marks and debris flow deposition volume estimates to derive the debris flow peak flow rate theoretically. They established the relation presented in E. (6), that agrees with the observed relationships reported in Japan by *Mizuyama and Uehara* [1984].

$$Q_{sp} = 0.002 \Sigma V \quad (6)$$

The debris flow total income volume (ΣV) is estimated as proposed by *Mizuyama and Uehara* [1984] where the volume of expected sediment runoff

corresponds to debris flow single wave and can be computed as the planned sediment runoff volume (section 3.2).

For the second method, to estimate the debris flow peak flow rate is necessary to compute the water peak flow rate. Assuming small watershed basins (less than 5 km² of drainage area) the Rational Method can be adopted as represented by Eq. (7).

$$Q_p = CIA/3.6 \quad (7)$$

Where: Q_p is the water discharge peak flow rate (m^3/s), C is the runoff coefficient, I is the design rainfall intensity (mm/h) and A is the watershed drainage area (km²).

Intensity-duration-frequency (IDF) rainfall equations are one of the most used methods to predict rainfall intensity (I) in engineering design in Brazil. Otto Pfafstetter published a pioneer study for IDF equations in Brazil [Pfafstetter, 1982]. Recently, updated equations for the main Brazilian cities shall be easily found in the literature, such those ones presented in *Festi* [2006]. The runoff coefficient also can be obtained in the literature based on the soil type, gradient, permeability and land use in the studied watershed.

Finally, the computed water discharge Q_p (m^3/s) can be converted in debris flow peak flow rate Q_{sp} (m^3/s) by applying the relationship presented in Eq. (8).

$$Q_{sp} = \frac{C_s}{C_s - C_d} Q_p \quad (8)$$

Where, C_s is the volumetric concentration of sediments in torrent bed (assumed to be about 0.6 in the absence of better estimations) and C_d is the volumetric density of sediments in the debris flow computed by Eq. (3).

3.4 Flowchart for countermeasure selection

The Brazilian manual incorporated a flowchart (see Appendix) to help the process of defining the appropriate set of debris flow countermeasures. The flowchart considers the hydrographic basin physics elements as topography, debris flow characteristics and also the socio-economic aspect of the flooding area. The flowchart offers objective guidance that leads to the definition of a suitable countermeasure solution based on the answers to specific yes/no questions. Prior to applying the flowchart, the following steps should be followed, including a field investigation with a general geologic characterization of the study area.

- (a) Establishing the sediment movement forms areas according to the zones presented in **Fig. 3** (occurrence area, flow area, deposition area, bed load area).

Fig. 8 Breast height coefficient as a function of the height of the tree based on *Soares et al.* [2009] equations for five Brazilians native species.

- (b) Identification of unstable hillslopes areas.
- (c) Location of the planned countermeasure : in the valley or on the hillslopes.
- (d) Position of protected objects : in the flow area or deposition area.
- (e) Identifying how the protected objects are distributed.
- (f) Position of the planned countermeasure : upstream or downstream from the planed reference point.
- (g) Type of debris flow matrix : muddy type or gravel and soil type.

This guided process is just an outline to help engineers and other technicians in countermeasure allocation, especially because of the lack of considerable expertise in debris flow countermeasures design in Brazil. The flowchart should be applied carefully with reasonable judgment since misinterpretations could lead to a non-adequate choices for debris flow mitigation.

4. CASE STUDIES

Based on the discussed methodology, the guidelines of the Brazilian Manual for countermeasures against debris was applied in two pilot projects : the first one in Nova Friburgo, Rio de Janeiro state, and the second one in Blumenau, Santa Catarina state. Both areas have experienced debris flow events and are considered high-risk areas according to a risk map developed as a product of another branch of the GIDES project.

4.1 São Lucas Hospital case, Nova Friburgo-RJ

In 2011, between January 11th and 12th, an intense rain triggered numerous slope failures and debris flow in the mountain region (Região Serrana) of Rio de Janeiro state. These occurrences caused the greatest Brazilian disaster, with 905 casualties in seven cities, affecting over 300,000 people (42% of Rio de Janeiro Municipalities were affected) [World Bank, 2012 b]. One of the affected areas was the one where the São Lucas Hospital is placed. The São Lucas hospital is located in the north-western area of Nova Friburgo City, in Rio de Janeiro state and serve as a reference for several habitants of the region. **Figure 9** (a) shows the Rio de Janeiro state map indicating the location of Nova Friburgo municipality. **Figure 9** (b) presents a view from the top of the study area.

On January 12th, the maximum 1-hour rainfall volume reached 42.8 mm, and the daily precipitation reported was 109 mm. The registered death toll was 20 people and several houses and infrastructure facilities were destroyed around the directed affected area. Field

surveys indicated that the debris flow occurred mainly by eroding the river bed and riverside slopes of a mountainous torrent gully in a reach of 200 m upstream from the hospital building. The drainage basin area upstream is about 0.075 km², and mean thalweg gradient is 1/5(=11°).

The riverbed and hillslope are composed by colluvial deposits and residual soil of granite. Both contain large blocks of rock with diameters ranging from 5-10 m, but also enclosed fines, mainly silt and clay, with a composition over 40%. The thickness of the residual soil layer is about 5 m. **Figure 10** shows a schematic plot of the thalweg. The letters in parentheses (a, b, c, d) represent points where pictures were taken. These pictures are presented in **Fig. 11**. A top view from the watershed area is also indicated in **Fig. 11** (e). The numbers inside the squares are points where cross sections were sketched from field data.

For the design rainfall it was considered a daily rainfall event of 189 mm for a 200 years return period. The planned sediment runoff volume computed was 10,873 m³, and the planned driftwood volume was 55 m³, resulting in a total debris flow volume of 10,928 m³.

The flowchart was also applied and suggested a closed type sabo dam, according to the following

Fig. 9 Site study overview. (a) Rio de Janeiro state and Nova Friburgo municipality. (b) A view from the top of the study case area.

judgment.

- (a) Is the countermeasure located in the Occurrence Zone? No
- (b) Is the countermeasure located in the Flow Zone?

Fig. 10 Schematic longitudinal plot from the torrent

Fig. 11 (a, b, c, d) Pictures taken from the site indicated in the schematic longitudinal profile plot in Fig. 10. (e) Topview from the watershed area

Yes

- (c) Is the zone eroded severely? No
- (d) Is the protected objects in the Flow Zone? No
- (e) What is the type of debris flow matrix? Muddy type

In this case, considering that large blocks of rock might move in direction to the dam causing structural damages, a debris flow breaker was proposed to reduce the mobility of the rock blocks. The debris flow breaker was positioned upstream from the main dam so that the water could be drained and the velocities of the blocks of rock reduced. The debris flow breaker has about 10 m width and 55 m length. Then main dam has about 14 m height in the highest section and 73 m length. The distance between the debris flow breaker and the main dam is 120 m. Figure 12 shows a draft design of dams.

4.2 Fortaleza Alta, Blumenau-SC

Fortaleza Alta is a suburb neighborhood of Blumenau city, in Santa Catarina state. In 2008 one of the greatest disasters occurred in Santa Catarina state, with a total loss estimated in US \$1.2 billion [World Bank, 2012 b], 106 deaths and 5,617 people displaced. Most of the losses were caused by slope failures and flood events. However, a debris flow event took place in Fortaleza Alta triggered by a 251 mm daily rainfall in Blumenau.

The characteristics of the site location can be summarized as follows.

- (a) Drainage basin are of 0.10 km².
- (b) Mean thalweg bed gradient : 1/3.4 (=16.5°).
- (c) Main bed material : soil and gravel including stones.

Figure 13 shows a current evidence of the previous debris flow event in the study area.

Given the specific characteristics of the rainfall intensity in this location a return period of 500 years was adopted resulting in a design rainfall of 230 mm daily. Based on this result, the total debris flow volume computed was 14,200 m³.

Fig. 12 Sketch of the basic location design of the Sabo dam proposed for the São Lucas Hospital case study.

Fig. 13 Fragments of rock immersed in the debris flow material of the event of 2008.

Again the Brazilian Manual flow chart was applied indicating a closed type sabo dam, according to the following judgment.

- (a) Is the countermeasure located in the Occurrence Zone? No.
- (b) Is the countermeasure located in the Flow Zone? Yes.
- (c) Is the zone eroded severely? No.
- (d) Is the protected objects in the Flow Zone? No.
- (e) What is the type of debris flow matrix? Gravel and sand type.
- (f) Is the countermeasure directly close to the protected objects? Yes.

Figure 14 presents a draft of the debris flow countermeasures to be considered in the plan.

5. CONCLUSION

The development of the countermeasures guidelines for debris flow under GIDES project reached its final year. A preliminary version of the Brazilian Manual for countermeasures against debris flow was written and is now being evaluated by a public inquiry given that this first issue is open for public consultation in Brazil.

Fig. 14 Sketch of the countermeasure planned for Fortaleza Alta, Blumenau, Santa Catarina.

One of the interesting novelty available in the manual is the flowchart to guide the definition to the most suitable type of Sabo dam. It is believed that this approach will be useful in providing Brazilian municipalities experts with significant insights in defining the type of sabo dam to be considered in different contexts.

After the adjustments to be defined by the open consultation, the Brazilian manual will be the first national guidelines for debris flow countermeasures providing a remarkable achievement in this field for the academic and technical community in Brazil.

ACKNOWLEDGMENT : The authors are especially grateful to JICA/GIDES team for all provided support that made this work possible.

REFERENCES

- Cruz P. T., Massad F., Kanji M. A. and Araujo Filho, H. A. (2004): Concepts on the design of dams for debris flow mitigation. 9th International Symposium on Landslides, Rio de Janeiro. Balkema, 2 : 1643–1650. <https://bdpi.usp.br/item/001437499>
- Festi, A. V. (2007): Collection of extreme rainfall equations in Brazil (original version in portuguese). XVI Simpósio Brasileiro de Recursos Hídricos, São Paulo, Brazil.
- Ishikawa, Y., Mizuyama, T. and Fukusawa, M. (1989): Production and flow mechanisms of a debris flow including driftwood, Journal of the Japan Society of Erosion Control Engineering, Vol. 42, No. 3, pp. 4–9. (in Japanese with English abstract)
- Kanji, M. A., Cruz, P. T. and Faical, M. (2008): Debris flow affecting the Cubatão Oil Refinery, Brazil. Landslides (2008) 5 : 71. <https://doi.org/10.1007/s10346-007-0110-3>.
- MLIT-Ministry of Land, Infrastructure, and Transport of Japan. (2007): Manual of Technical Standards for Establishing Sabo Master Plans for Debris Flows and Driftwood, Technical Note of National Institute for Land and Infrastructure Management, No. 364. (in Japanese)
- Mizuyama T. and Uehara, S. (1984): Study of results of observations of debris flow depth and flow speed, Journal of the Japan Society of Erosion Control Engineering, Vol. 37, No. 4, pp. 23–26. (in Japanese)
- Pfaffstetter, O. (1982): Extreme rainfall in Brazil (original version in portuguese). DNOS. Rio de Janeiro, Brazil.
- Silva, J. A. A. and Paula Neto, F. (1979): Basic Principles of Dendrometry (original version in Portuguese). Departamento Ciencia Florestal; Universidade de Brasília, Brasília, D. F. (Brasil). Dept. de Engenharia Florestal.
- Soares, C. P. B., Martins, F. B., Leite Junior, H. U., Silva, G. F. and Figueiredo, L. T. M. (2011): Hipsometric, volumetric and taper equations for eleven Brazilian native species, Revista Árvore, Vol. 35, No. 5, Viçosa, Brazil.
- Takahashi T. (1978): Debris flow occurrence and flow mechanism, Tsuchi to kiso (Soil and Foundations), Vol. 26, No. 6, p. 46.
- Takahashi, T. (1991): “Debris Flows”, Monograph Series,

Balkema. 1991.

World Bank (2012 a) : Loss and Damage Evaluation : Rio de Janeiro mountain region Flash Flood and Land Slides- January, 2011 (original version in portuguese). pp. 13-23.

World Bank (2012 b) : Loss and Damage Evaluation : Santa Catarina Flash Flood-November, 2008 (original version in Portuguese). pp. 26-46.

Received : 5 November 2016

Accepted : 31 July 2019

APPENDIX