The increasing natural disasters occurrence in Brazil is an inevitable issue to provide worthy urban settlements. The Programa de Aceleração do Crescimento (Growth Acceleration Program, better known as PAC) actions have been supported by Brazil’s Federal Government since 2007 aiming landslides risks prevention and mitigation. This actions support municipalities in elaboration of risk mapping, and the planning and execution of retaining structural works on the slopes. The purpose of this case study is to test and evaluate the flowchart for typology work selection for slope stabilization, which was designed from a partnership between Japan International Cooperation Agency (JICA) and the Brazilian Ministry of Cities as part of the “Manual for Elaboration of Structural Intervention Plans for Mass Movement”, in the GIDES (Strengthening National Strategy of Integrated Natural Disaster Risk Management) Project framework, obtaining the information from the executive projects reports of the works in the municipalities of Nova Friburgo, State of Rio de Janeiro (RJ), and Salvador, State of Bahia (BA). It was observed in the case study that the flowchart leads to solutions that are similar to what the executive projects had pointed out, such as: retaining structures; slope surface protection; and surface drainage. The work in Nova Friburgo was designed and executed to utilize deep subsurface horizontal drainage (PH drains), however when using the flowchart was not observed in the application of this result, due to groundwater level (G. W. L.) absence. The flowchart is an appropriate tool for the geotechnical solution for slope stabilization definition and selection against landslides.

Key words: slope, retaining structure, flowchart, case study

1. INTRODUCTION

1.1 Vulnerability of Brazilian settlements and federal government actions

The vulnerability of major Brazilian cities and its urban enterprises to landslides has a relationship with the country’s historic inability to provide decent and adequate housing for the population, and to support a land planning policy which enforces public interest over land owners’ private interests [Carvalho and Galvão, 2013]. Still, as stated by Carvalho and Galvão [2003], the disasters observed in Brazil are associated with natural and anthropogenic causes.

Annually dozens of people are killed and thousands are affected due to disasters [Dourado et al., 2012]. The growth of natural disasters occurrence and the population increase are directly related and the number of disasters has risen in recent decades [Marcelino et al., 2006]. According to Macedo and Martins [2015], the frequency of landslides and victims (deaths) by gravitational mass movements varies widely through the country.

To face these situations, in 2007, the Brazilian Federal Government created the “Programa de Aceleração do Crescimento” (Growth Acceleration Program, better known as “PAC”) to mitigate and reduce structural problems in the country. Since 2003, with the foundation of Ministry of Cities, it has been carried out structural and non-structural interventions (measures) for risk and disaster prevention, with the main focus on risk reduction in urban slum areas. However, the support actions for build up plans, engineering projects and the execution of slopes retaining walls works effectively started in 2010 with PAC.

The first actions were the construction of a methodology for the preparation of the Municipal Plan for Risk Reduction (PMRR), which covers the social...
participation and a qualitative risk mapping methodology for the prioritization of locations for the execution of the works. Thus, later, there were investments in support of the municipalities in the elaboration of the PMRR, slope stabilization projects and execution of slopes retaining walls works. These actions began to be treated as a priority in the PAC context, called PAC-Contenção de Encostas (PAC-Slopes Retaining).

Since the enactment of Law no 12,608, of April 10th of 2012, which established the National Policy of Civil Protection and Defence, were consolidated actions and the Program of National Risk Management and Disaster Response that has four axes of operation (mapping, prevention, response, and monitoring and alerting). Among other actions of the Federal Government, the slopes retention works (PAC-Contenção de Encostas) are inserted in the prevention axis.

1.2 Selection of priority areas and municipalities

The financial resources for slope retaining walls works are first pointed out by the Federal Government’s Annual Budget law. So that, the Heads of the Executive branch of State and Municipal Governments can request support to the Ministry of Cities.

The engineering projects can be supported since they are focused on an economically viable solutions in urban settlements of high (R 3) or very high (R 4) risk (see risk mapping methodology in Carvalho et al. [2007], and also in Macedo et al. [2013]). These projects may include the stabilization, retaining or slope protection of soil or rock, surface and subsurface (groundwater) drainage, environmental recovery and the registration of housing units and families, in cases of the relocation or resettlement. Still, families that are involuntarily displaced must be assisted by housing programs driven by Local, State or Federal Government, such as PAC-Minha Casa, Minha Vida (My House, My Life).

The actions of the PAC-Contenção de Encostas have its focus in 133 priority municipalities that have a higher probability of disasters occurring.

For the definition of the priority municipalities, the following criteria was adopted: (i) the frequency of the occurrence of landslide was obtained through the records of the bodies of the National System of Civil Defence; (ii) magnitude of events through the record of fatalities from the Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT) database; and (iii) the potential conditions of the occurrence of landslide events as established by geological predisposition evaluated by the Brazilian Geological Survey (CPRM) [Carvalho and Galvão, 2016].

Among the various municipalities that received investment and Federal Government support are Nova Friburgo/RJ and Salvador/BA, the cities focus of this article, which suffered 441 and 195 fatalities, respectively, between 1988 and 2015, both being among the 10 cities most affected by fatalities due to gravitational mass movements [Macedo and Martins, 2015].

According to Dourado et al. [2012], the 2011 Região Serrana (Mountainous Region) do Rio de Janeiro (RJ) disaster, which occurred between January 11th and 12th of 2011 in seven cities, caused 947 deaths, 300 missing, 50,000 homeless and about 1,000,000 of people affected.

1.3 Investment and execution of PAC

Since 2010, when the PAC-Contenção de Encostas was started, were hired entrepreneurs totalling US$ 978 million over 9 Brazilian States. The Ministry of Cities through PAC-Contenção de Encostas supported Nova Friburgo/RJ and Salvador/BA with US$ 61.1 million and US$ 76.1 million, respectively (R$ 2.3244 = US$ 1.00 exchange rate at November 11th, 2013, last date of investment selection).

1.4 GIDES project, manual and its flowchart

The concerns and the broad mobilization resulting from the remarkable 2011 Região Serrana do Rio de Janeiro disaster, besides the very known Japanese expertise on disaster and risk management, led Brazilian authorities to propound an international cooperation agreement with Government of Japan.

The Technical Cooperation resulted in the Project for “Strengthening National Strategy of Integrated Natural Disaster Risk Management” (hereinafter referred as the “GIDES Project”), in the context of the partnership between the Japan International Cooperation Agency (JICA) and the Brazilian Government, under the leadership of Ministry of Cities, was undertaken on July 31st of 2013. Brazilian Government and Japanese technical teams were cooperating for risk and disaster management improvements until November 2017, when GIDES Project was concluded successful.

One of the GIDES goals was the formulation of a Manual to guide the elaboration of intervention plan against mass movement and slope failure. The main offered technology of the manual is a flowchart (Appendix 1) on selection of the solution and typology of the slope stabilization intervention, which was designed as part of the “Manual for Elaboration of Structural Intervention Plans for Mass Movement”. A draft was verified in last phase of the GIDES Project and the Manual is under revision process led by Ministry of Cities.

It is important to mention that the Manual and its
flowchart, based on Japan Sabo Association (2007), were developed in order to offer an understandable and easy application method to be used by local governments, especially with low institutional capacities, in need to select the best geotechnical solutions for slopes stabilization and, eventually, to present better proposes to access financial support from Federal Government. Thereby, the analysed flowchart is composed by a sequence of simplified questions, which can be answered even by less experienced technicians and managers.

2. OBJECTIVE OF THE STUDY

This study aims to compare the conventional method and the flowchart to select intervention work for mass movement and slope failure, in order to verify availability of the Manual’s flowchart for typology work selection to slope stabilization, which was developed in the framework of the GIDES Project. Furthermore, the results of the comparison should be feedback to improve the Manual.

Considering the conventional method, this paper emphasis is on analyse the geotechnical solutions suggested by the construction companies reports for two slope retaining works in Nova Friburgo/RJ and Salvador/BA, Brazil, which were supported by investments from PAC, over again, comparing and focusing on the flowchart for typology work selection, with geological-geotechnical features.

3. METHODOLOGY

3.1 Case study area

It was selected two regions for the implementation of case studies: i) the Floresta Neighborhood, Conselheiro Paulino District, in Nova Friburgo, in the Mountainous Region of the RJ State (Fig. 1), which during the dawn of January 12th, 2011 were recorded 231 mm/24 h rainfall [Silva and Pinto, 2013, cited by INMET, 2011], among other events of December 20th of 2010 to January 13th of 2011; and ii) the Palestina Neighborhood, near the (quarry) Pedreira Limoeiro and Getúlio Vargas street, Salvador, State of Bahia (BA) (Fig. 2), emphasized a very high risk area (R 4) [Azevedo and Rocha, 2014].

3.2 Case study data

Executive project reports were used for the slope retaining works of Nova Friburgo/RJ and Salvador/BA, noting the key information and parameters that underlie the design and execution of geotechnical solutions, according to the works of Silva and Pinto [2013] and Azevedo and Rocha [2014].

All information and evidence from the field inspections were described in this case study for comparison with the possible geotechnical solutions suggested by the flowchart/decision tree. Thus, observing the geological and geotechnical characteristics the Ministry of Cities technical team conducted some exercises to test the flowchart, previously described on item 1.4, using the data and information of cases of Nova Friburgo/RJ and Salvador/BA.

3.3 Executive plan of nova friburgo, Rio de Janeiro (RJ)

The characteristics of the physical environment as a result of geological-geotechnical mapping of the Floresta Neighborhood, in Nova Friburgo/RJ according to Silva and Pinto [2013], are: i) the consolidated material consists of rock mass bursts, which exposes the granitic sound rock and granitic weakly weathered rock, very resistant and little to moderately fractured, with an expansion joint (stress relief) of about 30 cm, isolating and destabilizing the rock fragments. The rock blocks can have varying sizes, being isolated and/or partially immersed in soil (colluviums and talus soils). In rotary investigation (drilling) values of Rock Quality Designation (RQD) ranging from regular to good (between 50% and 90%), from a 3.5 m depth, were observed. In the portion, where the rocky massif takes over, the slope reaches 70 m height (section 1, Fig. 2). A total of 27 drill hole (polls) for the characterization of the consolidated (and unconsolidated) material were made; and ii) the unconsolidated material is formed by silty colluvium clay-soil over residual silt-sandy soils, reaching about
30 m thickness. In some parts the colluvial maybe soft soil with a thickness from 2 to 6 m;

The occurrence of landslide in the Floresta neighbourhood originated 3 scars and in one of them there is an outcrop of rock mass (left at 1, Fig. 1 and 3) and the other areas are exposed to erosion (right in 2 and 3, Fig. 1 and 3), where the soil is thicker. The sections 1, 2 and 3 show 20° to 23°, about 30° and approximately 51° of the inclination of slopes, respectively (Fig. 3) [Silva and Pinto, 2013].

According to Silva and Pinto [2013], the presence of wastewater and sewage being released downstream of the slope were observed.

The total investment for the project’s elaboration and for the execution of works in the Floresta neighbourhood in Nova Friburgo/RJ was US$ 4,900,461.93, with conclusion planned for 2016.

The following engineering solutions for stabilization of broken embankments were adopted, according to sections 1, 2 and 3 (Fig. 1 and 3) [Silva and Pinto, 2013]: (i) fix rock chips using rods and anchored concrete pillar buttresses, in the section 1; (ii) anchored (retaining) wall in the upper portion of the slope resting on rock, near the street Aureliano Barbosa Faria, in section 1 and 2 (Fig. 4); (iii) green nailed soil (passive anchor CA-50 steel of 25 mm diameter and variable spacing between 1.5 m and 2.5 m and plant geomat (geosynthetic cloth) reinforced with metal mesh) to the sections 2 and 3; (iv) demolition of housing units, in sections 2 and 3; (v) earthworks cut, in part of section 3; (vi) surface (runoff) drainage, with triangular ditches and waterfalls (stepwell/hydraulic stairs); (vii) applying deep subsurface horizontal drainage (deep PH drain) in the cutting zones and the middle slope, in the sections 2 and 3; (viii) drainage gallery for driving the surface water flow (runoff) through gabion retaining walls in sections 2 and 3 with dissipation; and (ix) reforestation areas exposed to erosion, in sections 2 and 3.

In the engineering basic project was suggested to use dynamic barriers of wire mesh in order to hold superficial splinters of rock and it was rejected, since the passive anchors are more economical and simple to perform/execute [Silva and Pinto, 2013]. For the work design was used the software, Slope/W of Geo-Slope Internacional Ltda., applying the Spencer Method for the stability analysis of the slopes [Silva and Pinto, 2013]. Geotechnical parameters for design and safety factors obtained are detailed in Table 1.

3.4 Executive plan of Salvador, Bahia (BA)

The geological-geotechnical attributes of the Palestina neighborhood, near the Pedreira Limoeiro and Getúlio Vargas street, in Salvador, Bahia, according to Azevedo and Rocha [2014], are: i) The consolidated material belonging crystal domain, called granulite, and coverings of Barriers Groups (Grupo Barreiras); and ii) the granulite can result in a silty to silt-clay unconsolidated material, soft and moderately compactness, up to 30 m thick and the presence of less resistant soil at up to 5 m deep, the geotechnical parameters presented higher values of c’ eφ in intermediate layers of soil (see Table 2) and at the bottom of the slope are colluviums and talus soils. According to Azevedo and Rocha [2014], the slope
at Pedreira Limoeiro is continuous and has a thick layer of soil, amphitheatre-shaped, with surface breaks, especially on the upper portion accompanied with a wide vegetation cover, of about 70° of slope and height of 15 m (Fig. 5). There was a lot of rubble and garbage thrown at the foot of the slope, uncontrolled release of sewage and rainwater without control that increase the superficial erosion [Azevedo and Rocha, 2014].

There was no evidence of geological-geotechnical features which induce preferential landslide wedges. Also groundwater levels (G. W. L.) were not observed in the polls (boring log) for the execution of the projects [Azevedo and Rocha, 2014].

The housing units and buildings built in the risk area have up to two floors, ceramic block masonry with concrete structure and foundations, which is in the most part shallow foundations [Azevedo and Rocha, 2014].

In turn, US$ 2,797,640.67 was invested for the implementation of projects and for the execution of works in the Palestina neighborhood. 280 families were benefited from the work.

To retain the hillside Pedreira Limoeiro, it has been adopted soil nailing solution (Fig. 6), with a galvanized steel wire mesh Q-61(0.97 kg/m²) and shotcrete (fck> 25 MPa), from the top to the contact with the layer of soil and rock, with weep hole (short drains) at the foot of the slope (to assist in drainage of coating/facing) and trapezoidal ditches with 30 cm base and 30 cm height at the slope crest, divided into 4 panels (Fig. 7) [Azevedo and Rocha, 2014]. The dimensions and spacing of the installed nails vary according to the execution, as confirmed in Table 3.

For the work design was used the software Slide by RocScience Inc., applying the Bishop Simplified Method (Equilibrium Limit) for the stability analysis of the slopes, and the softwares CANAL and Pluvio, of the Federal University of Viçosa, for hydraulic design [Azevedo and Rocha, 2014]. Geotechnical parameters for design and safety factors obtained are detailed in Table 2.

Table 2 Geotechnical parameters and safety factors for Salvador /BA case study [Azevedo and Rocha, 2014]
|   |   |
|---|---|
| $c'$ (cohesion) | 15.6 kPa for saturated soils, about 10 kPa for soil top layer and about 60 kPa for soil intermediary layers. |
| $\phi$ (friction angle) | 29.4° for saturated soils, 18° for soil top layer and about 25° for soil intermediary layers. |
| SF (Safety Factor) | Between 1.16 and 1.21 before the work. After the work the values were between 1.58 and 1.77. |

3.5 Flowchart in the manual

The conventional method to select intervention work for slope failure is normally conducted by specialist with substantial experience based on geological-
geotechnical characteristics of a site.

On the other hand, a flowchart is being introduced in the Manual to help less experienced engineers in selecting intervention work, considering shortage of experienced engineers in the municipalities. The flowchart was quoted from a Japanese manual and arranged considering the Brazilian geological features and the most used geotechnical engineering solutions (Appendix 1).

Prior to using the flowchart, field inspection is required to collect data such as: i) topography; ii) surface-ground water; iii) geological-geotechnical characteristic; iv) vegetation; v) rupture history (inventory); vi) existing intervention work; and vii) land use.

Selection of intervention work is proceeded with according to step of the flowchart in the following procedure:
1. To answer the 1st question described in the diamond symbol in the flowchart;
2. To answer the question based on the field inspection data;
3. To judge YES or NO according to the Table judgement criteria (Appendix 2);
4. To proceed the pass, and select a intervention work;
5. To proceed next question, and repeat the same process as in number 1 to number 4, until the end of the path.

It is important in the selection of intervention work with the flowchart to ensure the field inspection and to improve the judgement criteria.

The flowchart presents a functional typology but no specific type of intervention works. Therefore another process supplements the flowchart to select specific type. The procedure presents a table (Appendix 2) that enables to select specific type of intervention work based on supposition of slope rupture.

4. RESULTS

The result of tests conducted by the Ministry of Cities team to assess the qualification of the flowchart is shown below.

4.1 The use of flowchart

According to the steps of the flowchart the following answers and justifications were recorded, which shows the number of questions (the diamonds) and the responses to section 1 (Fig. 1) of the Floresta neighborhood in Nova Friburgo/RJ:

- 1 - Is the slope stable? No. There is a small colluvial soil layer on unstable rock, however, even after the first slope rupture, there is material prone to slide and damage the houses at the top and foot of the slope;
- 2 - Is it possible to cut slope to stabilize? No. Doing earthwork cut in rock and the space to make it at the top of the slope is inadequate, with many housing units. Furthermore, the rock slope is very high (about 70 m);
- 3 - Is it possible to build retaining structure works to stabilize the slope? Yes. Depending on the type of work selected for the case studied;
- 4 - Should it keep the vegetation considering environment protection? No. The vegetation in the location in the rock mass is scarce and does not exert any risk prevention function and surface protection. The weight of the wedge vegetation on the thin topsoil cover can lead to new ruptures.
- Decision — Slope Retaining Works
- 5 - Is it effective groundwater drainage works? No. The granitic rock slope does not allow water storage, moreover it is little fractured, which does not justify G.W.L. drainage.
- 7 - Is it effective surface water drainage works? Yes. The surface water flow must be directed downstream from the slope top along the rocky massif.
- 8 - Is it necessary surface protection works? No. The slope is in outcropping and weakly weathered rock, not justifying any surface protection of the slope.

Still observing the flowchart steps the following answers and justifications for section 2 (Fig. 1) of the Floresta neighborhood in Nova Friburgo/RJ were recorded:

- 1 - Is the slope stable? No. Despite the slope has already failure, there is still material to be mobilized and the slope has more than 30° of inclination. Also, there is presence of wastewater released on slope;
- 2 - Is it possible to cut slope to stabilize? No. The slope is unstable, has height greater than 30 m and little space for earthwork cut execution, due to the proximity to the buildings;
- 3 - Is it possible to build retaining structure works to stabilize the slope? Yes. Because it is greater than 30 m and have the presence of buildings and infrastructure (via), this will not be removed from the slope top;
- 4 - Should it keep the vegetation considering environment protection? Not applicable. The site is already cleared/deforested;
- Decision — Slope Retaining Works
- 5 - Is it effective groundwater drainage works? No. It was not observed G.W.L. in the boring logs, even though they were held in the rainy season, according to the surveys presented by Silva and Pinto [2013];
- 7 - Is it effective surface water drainage works? Yes. To drive waters downstream through the thalweg of the sections 1 and 2 (Fig. 1);
- 8 - Is it necessary surface protection works? Yes.
The region has exposed soils and subject to erosion.

Finally the flowchart took the following answers and justifications for Pedreira Limoeiro (Fig. 3) of the Palestina neighborhood in Salvador/BA:

• 1 – Is the slope stable? Yes. It is unstable because of the high slope gradient value;
• 2 – Is it possible cut slope to stabilize? No. There is no space for slope top cut, due to the presence of housing units at the top, as well as having outcropping rock at the slope foot;
• 3 – Is it possible to build retaining structure works to stabilize the slope? Yes. The soil is not competent (resistant) enough;
• 4 – Should it keep the vegetation considering environment protection? Not applicable. The site is already cleared/deforested;
• Decision – Slope Retaining Works
• 5 – Is it effective groundwater drainage works? No. It was not observed groundwater level in the polls, even though they were held in the rainy season, according to the surveys presented by Azevedo and Rocha [2014].
• 7 – Is it effective surface water drainage works? Yes. To directing and collect of runoff water;
• 8 – Is it necessary surface protection works? Yes. To protect the slope surface exposed soil to weathering and erosion.

4.2 Analysis of the flowchart solutions

Generally, the flowchart presented similar engineering solutions for those selected in the executive projects for sections 1 and 2 of Floresta neighborhood (Nova Friburgo/RJ) and the Palestina neighborhood (Salvador/BA).

For the Floresta’s sections 1 and 2 (Fig. 1) the flowchart led to executing retaining structures work. It is important to emphasize, that the flowchart does not specify the type of work of slope retaining, but only suggest using them. In both cases it was rejected the earthwork slope cut, which is a difficult solution to be applied in slums areas, where housing units are very close to the slopes top and foot.

When comparing with the executive projects of Silva and Pinto [2013] it was observed that there was the use of retaining structures solutions in sections 1 and 2 (anchored concrete pillar buttresses, anchored retaining wall and green soil nailing).

In section 2 (Fig. 1) the landslide mobilized soil and the upper vegetal part. This resulted in an exposed soil, which needs to be protected and this necessity was identified using the flowchart. In the executive project the soil nailing received a vegetal geomat to perform this function.

In the same section 2 (Fig. 1) the flowchart indicated that it would not be effective using the deep PH drainage, however, in the executive project was planned to execute the PH drainage [Silva and Pinto, 2013]. The authors of the project did not present justifications for the execution of PH drainage, while not observing G. W. L. in rainy season. However, it is important to emphasize that only the drill holes groundwater table data is not enough to resolve the use or not of PH drains.

In Brazilian tropical soils, where the profiles are predominantly unsaturated, the moisture change affects the slopes mechanical and hydraulic behavior. Maybe, it indicates an empirical technical decision of the authors based on their own experience in works with tropical soils to use the PH drains in section 2 (Fig. 1). As an example, the chemistry, mineralogy and structure properties of tropical soils have a great variability due to the hot climate and humidity which affects the physical and chemical weathering. So, the water rainfall destroys the tropical soils chemical cementation and its apparent cohesion, due to its unsaturated phase.

Nonetheless, in the situations pointed by the flowchart and the executive project [Silva and Pinto, 2013] were necessary engineering solutions for conduct the runoff.

For the works of the Palestina neighborhood (Fig. 2) the flowchart and the executive project [Azevedo and Rocha, 2014] led the slope retaining structures works (soil nailing), with no possibility of earthwork cut, slope surface protection (shotcrete), surface drainage (trapezoidal ditches) and without the groundwater drainage.

The absence of PH drain was not justified in the executive project of Azevedo and Rocha [2014]. However, they point the need of the execution of weep hole drains along the slope face, to assist in the slope face drainage.

Any type of drainage to decrease the pore water pressure in slopes may be appropriate; however its efficiency, applicability and economy can be questioned. The efficiency of the deep PH drains depends on the construction method and its maintenance, for example to avoid clogging, mainly in Brazil, where the investment in infrastructures maintenance is low. So, it is suggested to change the present question in the flowchart “(5) Is it effective groundwater drainage works?” (Appendix) to “(5) Is it required groundwater drainage works?”.

Hence, one should assess the need to use them and not their effectiveness of PH drains, even if the G.W.L. was not observed in the polls.

5. CONCLUSION

It was possible to estate that the use of a flowchart
can help properly less experienced technicians in selecting the proper engineering solutions for slope stabilization, depending on the geological and geotechnical characteristics of the site. However, this flowchart does not specify the types of retaining structures work to be applied, because it is not the object of analysis of these case studies.

As part of the “Manual for Elaboration of Structural Intervention Plans for Mass Movement”, it is important to mention that the flowchart will be complemented with information on tables for the specific selection of the type of retaining structure that must be executed, since it indicates in a general manner the need for solution. Also, it will be necessary to fill a form that requires basic information for the execution of works and characterization of the physical environment, which facilitates the determination of geological and geotechnical features.

Considering drainage as one of the main aspects of retaining structure slope work in tropical soils it is important to observe that the executive project indicates deep PH drains, however the boring logs do not show G. W. L., even in rainy season, and thereby the flowchart path studied did not lead to the execution of PH drains. It indicates a possible improvement suggestion to be considered in flowchart future revision, due to the behavior of tropical soils.

In Section 2, of Nova Friburgo/RJ (Fig. 1), Silva and Pinto [2013] suggest performing deep PH drains. While in Palestina neighborhood work, in Salvador/BA, the authors only used weep hole drains to capture the water that reaches the slope.

Still, the slopes instrumentation by means of piezometers during rainy and dry seasons can provide accurate information of slopes saturation conditions. In addition, there are many others field and laboratory tests to access the behavior of tropical soils. This can base with greater security and economy the application of deep PH drains, or any type of slopes drainage work in slopes retaining structures, mainly for development of basic engineering projects.

In all case studies the flowchart pointed for executing retaining structures slopes, also pointed in the executive projects. As well, there was the similarity of point to drainage solutions for runoff.

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APPENDIX 1 [Modified from Japan Sabo Association, 2007]
APPENDIX 2 [Modified from Japan Sabo Association, 2007]

| Judgment | Way of judgment or indicator |
|----------|-----------------------------|
| 1        | • In case that the existence of clear deformation is found in the slope as a result of site survey, the slope is judged to be not stable. An example of clear deformation is shown below. Cracks in the top side of the slope, small depressions, pit cavity, slackness between surface soil and natural ground, bending of the trees, swellings in the middle of the slope, over-hang, expansion of the joint in the dip slope, subsoil water from the wide area of the slope.  
• In case that the gradient is steeper than the minimum of the standard gradient of slope in the cutting slope, this slope is considered not to be a stable. |
| 2        | • Slopes with overhang, unfixed stone, sediment in terrace, slope talus, and strongly weathered rock, which are less than 30 m in height, are thought to be cut. However, if the slope section has been utilized as residential area, etc., it is impossible to be cut (do earthwork) unless there is no plan of housing relocation.  
• The long slope with more than 30 m in height and being generally unstable, is considered not to be cut. |
| 3        | • Retaining wall works, concrete crib wall works, anchored wall works and soil nailing are to be examined to be possible to achieve the overall stability. The criteria for judgment are shown below.  
• The slope with less than 15 m in height is considered to be stable by retaining wall works or combination of retaining wall works and concrete crib works.  
• Crib works are suitable for the stabilization of the high slope but the height limit for the slope is about 30 m. The cost is high when it gets to more height.  
• Anchored works are available for only stabilizing the partial part of the slope over 30m. |
| 4        | • In case of relatively shallow soil collapse that can be stabilized by fence or sediment retaining works and, hence, the trees are to be left untouched.  
• In case that the slope is in advantageous position for scenic view and the slope can be stabilized by anchored wall works in addition to fence or sediment retaining works, the trees are to be left untouched. A trial calculation of stability analysis by anchored wall works should be carried out in such a case. |
| 5        | • In case that there is the need of G.W.L. drainage, consider the efficiency in river head.  
• In case that there is the need of G.W.L. drainage, consider the efficiency at depressed ground where there is apt to concentrate groundwater and the G.W.L. vary in rainy season. |
| 6        | • Retaining wall works are required for a steep slope due to cuts and colluvial deposit of low bulk density.  
• In case that there is a unstable weathered rock or block on the middle of the slope, retaining wall works are required for this stabilization. |
| 7        | • In case of a slope with less than 10 m slope height and there being no surrounding rainwater inflow, surface drainage works are not necessarily required.  
• Even in the case of the above, in case that the slope surface is bare land or the slope is weak to erosion, due to sandy soil, surface drainage work is necessary. |
| 8        | • Slope protective works are necessary in order to keep the slope from erosion or weathering.  
• If it is feasible to protect the slope by vegetation, it should be given priority before other options.  
• Judging from the slope face condition, the slope protection by structure is adopted. |
| 9        | • In case that it is impossible to carry out cutting works or restraint works, gravity retaining wall is effective to catch up collapsed soil. Even if the entire collapsed soil is possible to be caught by gravity retaining wall, it is desirable to construct low priced surface drainage works.  
• In case that the collapsed soil cannot be caught by gravity retaining wall, it is required to construct groundwater drainage works and surface drainage works to decrease the frequency of occurrence of the collapse and to preserve human life by establishing an evacuation system. |