Causal Factor Quantification of Malaysian Landslides

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***Abstract*- Specifically reference to Malaysian region, number of landslides is tremendously increasing due to slope failures. Extensive studies on many cases of slope failures reveal the fact that it is not only the rainfall that is responsible for these disastrous events. In actual failures are mostly credited to human factors such as inattention, ineptitude, lack or pitiable maintenance system and ignorance of geological contribution. In this connection this paper demonstrated the tailored HEART technique to quantify the casual factors of Malaysian landslides. The technique of HEART is widely used to access human errors. Along with a problem of scarcity in data is also prevailing; such hitches have piloted by accounting non data reliant approaches like experts opinion approach and the same is followed by the author here for the application of the above mentioned technique.**

Keywords: Human Reliability, Error Producing Conditions, Performance Shaping Factors

I. INTRODUCTION

Industrial accidents such as Bhopal chemical release (1984), Three Mile Island (1979), Chernobyl and Radioactivity release disaster (1986) put the significance of human errors when managing risk systems [1]. In civil engineering among 500 reported failures of foundations, 88% was attributed to human errors [2]. In Europe about 800 cases of structural failures were investigated, which resulted that 75% damages and 90% of the cost of damage were due to human error [3]. Most structural failures were not due to variation in loads or resistances but as the outcome of human errors [3].

As referring among 49 major cases of landslides in Malaysia 88 percent were recognized to manmade slopes [4]. It is observed that poor design, incompetence, negligence and erroneous input data were the responsible agents of these slope failures [5]. Design errors such as abusing of the prescriptive method, construction errors such as over excavation or wrong side excavation and maintenance errors such as clogged drainage system were the prominent human errors observed by Malaysian construction industry [6]. when rapid increase in slope failures takes place in different regions of Malaysia. An attempt has been made to work out the likelihood of common human errors committed in the phase of construction like compliance of water cement ratio with given criteria, wrong twisting of the steel reinforcement etc but these are basically the nominal human errors [7], [8], [9], Human errors are committed throughout the whole life cycle i.e. planning, design, construction, installation, fabrication, and operation and maintenance stage. Stress due time pressure, lack of support resources during work execution, inexperience and unqualified personnel and organizational factors are all affecting human performance and hence potential for committing unintentional errors. Classification of human errors for slope works in phases of design construction and maintenance are shown in Table 1.

TABLE I
ENGINEERING CLASSIFICATION OF HUMANS ERRORS FOR SLOPE ENGINEERING

Design Errors	a. Improper/insufficient drainage facility b. Incorrect gradient c. Insufficient factor of safety d. Insufficient number of berms selected for slope height e. Design without complete knowledge of ground water conditions f. Inaccurate soil parameters
Construction Errors	a. Wrong/over excavation b. Poor compaction/improper removal of topsoil/unsuitable fill material
Maintenance Errors	a. Unrepaired clogged drains b. Unrepaired gulley formation c. Unrepaired/unnoticed surface and internal erosion d. Misunderstanding observed lateral movements/ground settlement

The objectives of this paper are:

i. To conduct a review of literature on slope failures, for investigation of its causal factors (focusing only Malaysian region)
ii. To apply/utilize tools for causal factors evaluation, borne at different stages of planning till maintenance
iii. To propose some remedial actions against those conditions/factors due to which slope failures/landslides are generating

It's a dire need now to work on those factors mainly responsible for the occurrences of slope failures. As already compared with world statistics, [4] in Malaysian region reasons of these landslides/slope failures are not geological or morphological (Fig. 1). Through some expertise interviews and opinions, belong to consultants and some from former staff of concerned division (Slope Engineering Division) list of error producing factors has been prepared as this is the major requirement of this study.

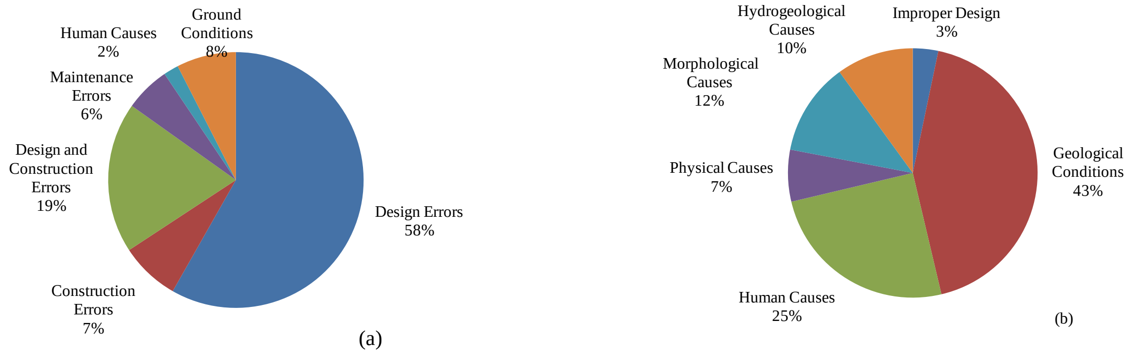

Figure 1. Statistical classification of failure: (a) Malaysia (b) Worldwide [4]

Concerned officials selected error producing conditions, which is dominating over design construction and maintenance tasks and subtasks, named as assessed proportion of affect (APOA). No doubt due to insufficient data results may not be so refined but at least what factors/conditions are more influential can be assessed by applying Human Error Assessment Rate Technique, HEART technique [10] [11]. In this particular technique of HEART [11] term of human unreliability is used instead of human error probability. Basically Human error probability (HEP) is the number of errors occurred divided by the total number of opportunities to occur. In calculating basic human error probabilities (HEPs) proportion of error producing conditions must be included.

II. Literature Review

Human reliability analysis proposed different methods to quantify human performances as human performances sometimes becomes big threat to structural reliability. As already point out by [12] [13] [14] that gross (human) errors bring changes in the probability of failure. Performance of an individual is in originally governed with many factors and in technical terms it is called Performance Shaping Factors or Error Producing Conditions (Table 2).

The approaches of Human reliability assessment have occupied two categories: one carrying databases and other totally relying on expert's opinion. The first category consists of those techniques which has already in hand generic error probabilities. These generic probabilities are than manipulate by the evaluator to extrapolate from the generic data to the particular scenario being considered. Technique for Human Error Rate Prediction (THERP), Human Error Assessment Rate Technique (HEART) can count under this category. Techniques lie in second category are not so structured, totally relying on personal communication and asking to estimate the probabilities of the specific situation. Examples of these category techniques are Absolute Probability Judgment (APJ) and Paired Comparison (PC). Success likelihood index method are also belongs to second category, but this technique follows a structured pattern. The generation of HEPs may therefore arise through expert's opinion or by combination of assessor's manipulation and interrogation of quasi-databases [10]. The most commonly used techniques are Technique for Human Error Rate Prediction (THERP), Success Likelihood Index Method (SLIM), and Human Error Assessment Rate Technique (HEART) [15], [16], [17],[18].

The APJ approach is also the most straightforward human reliability quantification approach. It simply relies on assumption that what people can remember, or predict directly on the basis of their experiences, is more authentic to estimate directly the chances of an event [19]. A panel of six is at least required for estimation; in case of more availability of experts estimation will become more refined. The ways adopted to aggregate their opinions are**:** Aggregated individual [19], Delphi [20], Consensus and Nominal group Method [21], [19].

TABLE 2.
PERFORMANCE SHAPING FACTORS [1]

External	Situational Characteristics	Quality of Environment Work Hours/Work Breaks
	Job and Task Instructions	Written/Oral Communications Work Methods
	Task and Equipment Characteristics	Perceptual Requirements Motor Requirements
Internal	Organisimic Factors	Motivations, Attitudes Previous Training/Experience
Stressor	Physiological Stressors	Fatigue Hunger/Thirst
	Psychological Stressors	High Jeopardy Risk Monotonous, Degrading, Meaningless Work

III. Human Error Assessment Rate Technique (HEART)

Calculation of HEART is dependent on generic error probability and related EPCs. Generic error probability has to be selected from the given criteria A-H according to focus situation EPCs carrying a maximum affect value, which has to be changed with the estimated proportion. Proportion of this value has been estimated by expert's opinions and a mean value is applied. As compared to other error rate prediction techniques it is quite easy. It requires only the perception of the user; no detailed calculations are involved in it. Its validity and accuracy is already confirmed through a large scale study of 30 tasks [10]. This can be applied to any industry where the human reliability has to be checked. A simple process is worked out on the basis of the following formula [11]

$$HEP = GTT[(EPC - 1) \times APOA + 1] \quad (1)$$

EPC = Error Producing Condition
GTT = Generic Task Type
APOA = Assessed Proportion of Maximum Affect

IV. METHODOLOGY

A. *HUMAN ERROR QUANTIFICATION*

Quantification of the human errors needs human reliability analysis. In the coming section probability of human errors has been worked out by applying HEART technique. Its validity and accuracy is already confirmed through a large scale study of 30 tasks [15]. The technique is flexible; it can be applied to any industry [22].The process of calculating HEP using HEART is summarized as follows:

a. Compile a list of subtask items lies under the category of selected tasks. Determine equivalent generic task types (GTT) equivalent in complexity to the subtasks and its nominal HEP.
b. For each identified subtask determine its error producing conditions (EPCs). There are more than 30 EPCs provided in HEART.
c. Error producing sources of the relevant tasks are worked out by previous literature/concerned authorities to match with the EPCs of the HEART technique.
d. For each subtask determine assessed proportion of affect (APOA). The determination of this parameter is based on expert's interviews and opinions.
e. HEP is determined using the basic simple equation already mentioned in the previous section.
f. Graphical representations of the results are drawn in Fig. 2. to Fig. 11.

A total of 46 subtask items out of three major tasks of design, construction, and maintenance are chosen on the basis of previous literature and through expert's interview/opinions. On the basis of their experience and judgments in three distinct phases of design construction and maintenance contribution of related error producing conditions EPCs and its affects named as APOA, are established. Generic task type situation, according to the complexity of the subtask has also been selected through already estimated ranges present in this HEART technique.

B. *EXPERTS DEMOGRAPHICS*

Among 15 experts, more than half belong to Slope Engineering Division JKR, leading consultant of Malaysian construction industry and one from IKRAM. Structured and non structured questionnaire are shaped up with attached format of the HEART technique. The research follows Aggregated Individual Method and Consensus Group Method to work on the expert's opinion strategy. These methods are preferable as the opinions obtained through them are unbiased. Secondly author considers it is less time consuming. Methods like Delphi and Nominal Groups require more than one round and do not allow the expert to answer independently. Expert's opinions details regarding GTTs, APOAs and other items can be furnished on the request of the reader.

V. ANALYSIS AND DISCUSSION

Graphical plots (as shown from Fig. 2 to Fig. 11 and Table 3. to Table 12.), reflects clearly that, under the category of Design Task, IP2 is the most dominating Input Parameter Selection Subtask. IP2 is related to, evaluation of soil shear strength parameter from experimental work that may or may not using triaxial testing technique that needs full expertise due to its complicated experimental setup. It can easily furnish misleading results if utilization of the technique is not in order. EPC of applying opposite technique/philosophy is mostly occurred when testing methods or really complex testing strategies have been followed. The parameters drawn from this technique is in actual the confirmation of the stability of the slopes. In this regard better option is to counter check the c-phi results from some other technique also. In case of having doubtful results, the only alternative is to avoid this technique.

Other subtask category under Design Task (as shown in Table 13.) which is highly under the influence of human errors is Feasibility Study Subtask (F1). This subtask clearly indicates that before the start of any of the project proper documentation from design to maintenance must be there. If talking in connection of slopes, information like slope locations, gradients and slope heights all (in case of natural slopes) has to be record first. What design strategies or construction methods are following? What maintenance issues have to be followed? The answers of all these questions have to be incorporated in this subtask item.

When discussing about its governing EPCs of mismatching between alleged and real situation, following ambiguous standards and principles the chances of risks has been increased. As risks cannot be assessed wholly through visualization; it requires the two basic parameters (probability of failure and consequences due to that failure) to predict its intensity. In this regard make sure that precautionary measures are decided on worst scenario basis. In designing ambiguous standards/practices are prevailing. This is in veracity not the EPC carrying out by the organizations. As this so called EPC is found mostly in approaches and checks used to design the slopes and slope strengthening structures. The technical specifications used in design drawings are also under the influence of this EPC. Commonly following Safety Factor Approach, method is one of the examples of ambiguous standards/guidelines. Stability of the slopes is not only governs with factor of safety but it is the reliability level which plays a vital role. In this connection, reviewing /reshaping of the ongoing principles by consulting the experts, are required. Incorporation of reliability based Load Resistance Factor Design approach is also one of the best solutions to minimize the influence of this EPC.

In Construction Tasks, subtasks items PW4 and PW5 poses significant error as construction of the retaining structures/walls are complex; these are composite structures bringing many structural elements together and this is not to be expected from an unskilled/inexperienced worker. For example in case of Soil nailed walls, spraying of concrete needs experienced skilled workforce. To minimize the effect of this EPC strict criterion has to be set and followed in terms of experience. In actual it's not an EPC but it's a deliberate error usually make for the sake of expediency. Organizations or concerned authorities must have to recognize the fact that safety should not be compromised at any cost. Criteria for experience have to be set according to the complexity of the task. Another solution is to follow the observational method with every ongoing activity.

In maintenance issue, special works category is showing high influence of human errors. In maintenance ground anchor structures structure needs extra care as chances of corrosion even due to soil moisture or environmental impact makes it vulnerable. Talking about its remedy a policy of Inspection, Communication Decision and Action ICDA has to be strictly followed to minimize the proportion of its EPCs.

TABLE 3.
DESCRIPTION OF DESIGN SUBTASK CATEGORY OF FEASIBILITY STUDY

F1	Developing plans include estimated time, cost of every activity involved in all the phases from design to till maintenance. Developing strategies to cover the task on what principles/standards in an allotted time period. Proposing alternatives if any of the activity hinders or discontinue.
F2	Reassessment of site investigation reports through site visits and material survey, including site history along with other details. All site investigation work must obey the acceptable guidelines.
F3	Planning of drainage system taking into consideration those areas where usually two monsoon seasons prevails and most of the time slopes failure occurs after heavy rains. Water carrying services must be properly equipped for all the worst conditions.
F4	Countercheck of survey data by studying topographical, hydrologic and land surveys maps of the considered site and the areas or facilities that may disturb by the work.

TABLE 4.
DESCRIPTION OF DESIGN SUBTASK CATEGORY OF INPUT PARAMETRES SELECTION

IP1	Determining basic soil parameters/index properties like soil density, plastic/liquid limit, through classification tests,
IP2	Evaluating of shear strength properties (includes effective and total stress strength parameters by triaxial testing method.
1P3	Establishing ground water table information that usually provides unbiased, relevant figures through geological survey.
IP4	Setting of gradient, with respect to class of slopes by keeping in view the stability of slope/risk levels.
IP5	Collection of rainfall data from Meteorological Department that includes intensity, duration and frequency of rainfall events.
IP6	Gathering of discontinuity data for rock slopes through rock outcrop mapping or in case of no exposure extrapolation is allowed, to establish possible failure modes.

TABLE 5.
DESCRIPTION OF DESIGN SUBTASK CATEGORY OF APPROACHES/CHECKS

AC1	A classical approach of safety factor frequently follows in. The factor of safety is capacity over demand and if value less than 1, than system will fail in that case.
AC2	Checking of overall stability of slopes. It depends on global safety factor approach, and internal and external stability on partial safety factors like consequence, material and load factors.
AC3	Checking the influence of surcharge loading such as fill or bank widening material (any extra weight on the slope) on the safety factors.
AC4	Designing of drainage facility according to GWT and rainfall intensity, in case of in adequate design or poor layout cycles of erosion will occur. Surface and sub surface drains all water carrying services like conduits; pipes are included under this facility. Cascade drains are preferable for easy maintenance.

TABLE 6.
DESCRIPTION OF DESIGN SUBTASK CATEGORY OF DRAWINGS/SPECIFICATIONS

DS1	Drafting of design drawings (for example slope angle, drainage system, laying depths of drains/pipes etc.) which are basically for practical implementation of the design tasks.
DS2	Providing guidelines for selection of fill material for embankment and backfilling.
DS3	Guidelines for temporary works like support system, borrow pits and measures to prevent erosion or gulley formation.
DS4	Maintain health. safety and environment

TABLE 7.
DESCRIPTION OF CONSTRUCTION SUBTASK CATEGORY OF EARTHWORKS

EW1	Drafting of design drawings (for example slope angle, drainage system, laying depths of drains/pipes etc.) which are basically for practical implementation of the design tasks.
EW2	Providing guidelines for selection of fill material for embankment and backfilling.
EW3	Guidelines for temporary works like support system, borrow pits and measures to prevent erosion or gulley formation.
EW4	Maintain health. safety and environment

TABLE 8.
DESCRIPTION OF CONSTRUCTION SUBTASK CATEGORY OF TEMPORARY WORKS

TW1	Controlling surface erosion to prevent channel formation using proven method.
TW2	Taking measures to prevent seepage erosion.
TW3	Maintaining high safety for temporary works according to design drawings and technical specification.

TABLE 9.
DESCRIPTION OF CONSTRUCTION SUBTASK CATEGORY OF PERMANENT WORKS

PW1	Fixing of slope angle
PW2	Increasing density of soil by soil compacting techniques through heavy reliable machinery.
PW3	Install surface and subsurface drainage systems to prevent surface erosion, infiltration and seepage erosion.
PW4	Stabilize slope through simple retaining walls to support the back soil/earth/ to resist lateral pressure of the soil.
PW5	Constructing other strengthening works that require specialized expertise such as soil nailing and mechanically stabilized earth.

TABLE 10.
DESCRIPTION OF MAINTENANCE SUBTASK CATEGORY OF ROUTINE MONITORING

RM1	Repair of leaked drain pipe or if portion of pipe is exposed.
RM2	Removal of unwanted material like tree roots/debris from slopes or from surface drains and from weepholes.
RM3	Repair of mortar joints of masonry walls to prevent infiltration.
RM4	Maintain landscape by repairing or replacing fencing/slope material
RM5	Covering of localized erosion spots to maintain the slopes stability
RM6	Regular maintenance of surface/sub surface drainage facilities.

TABLE 11.
DESCRIPTION OF MAINTENANCE SUBTASK CATEGORY OF ENGINEERS INSPECTION

EI1	Inspecting distress signs on slope mainly due to soil movements.
EI2	Search stability assessment reports to estimate whether standards and codes are followed in using design approaches.
EI3	Re access consequence to life category of slopes taking site condition, possible failure and retaining structures etc.
EI4	Strengthening works on retaining structures at regular intervals as preventive stabilization measure.
EI5	Immediate filling or repairing surface drain cracks, usually

	occurs by water pressure or soil movement
EI6	Observe ground settlement due to changes in soil properties /
EI7	Audit of routine works

TABLE 12.
DESCRIPTION OF MAINTENANCE SUBTASK CATEGORY OF SPECIAL MEASURES

SM1	Checking of surface or subsurface drains immediately after heavy rainstorms. Subsurface drains like horizontal drains and drainage blankets shall be provided for cut and fill slopes and especially in those areas where GWT is high.
SM2	Extra monitoring of prestressed soil or rock anchors due to possible corrosion used as reinforcement.
SM3	Monitoring of measures strictly specified by local authority (like JKR).

TABLE 13.
MAJOR TASKS AND HEPs

Design	HEPs
Feasibility study	0.48
Input parameters	0.49 (IP2)
Approaches/Checks	0.23
Technical Drawings/Specifications	0.005
Construction	
Earthworks	0.18
Temporary works	0.004
Permanent works	0.82 (PW5)
Maintenance	
Routine monitoring	0.18
Engineers inspection	0.5
Special measures	0.68 (SM1)

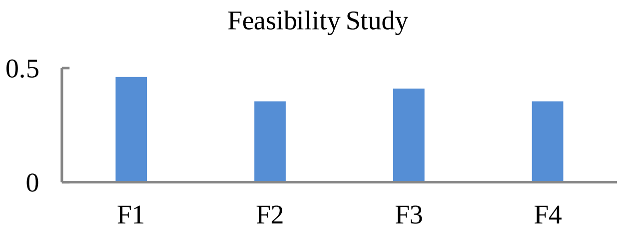

Figure 2. HEPs of Design Subtask Category of Feasibility Study

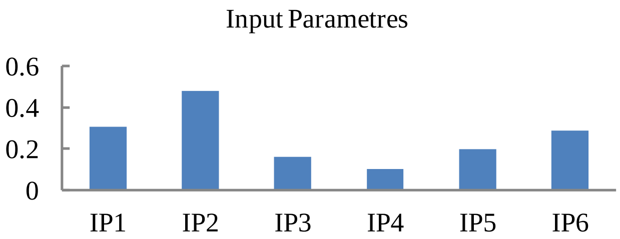

Figure 3. HEPs of Design Subtask Category of Input Parameters

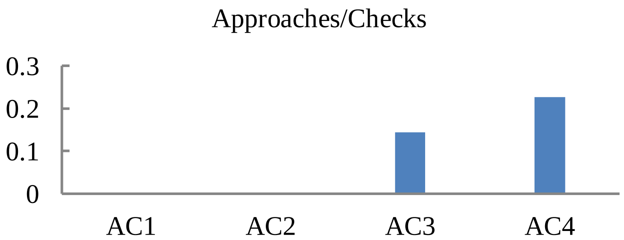

Figure 4. HEPs of Design Subtask Category of Approaches/Checks

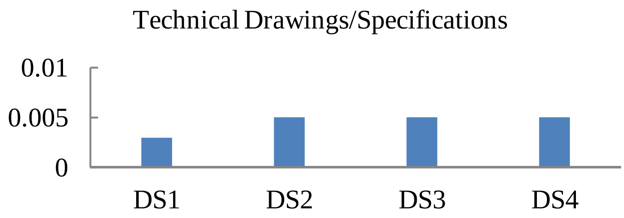

Figure 5. HEPs of Design Subtask Category of Technical Drawings

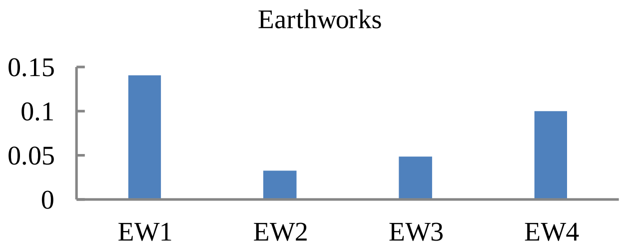

Figure 6. HEPs of Construction Subtask Category of Earthworks

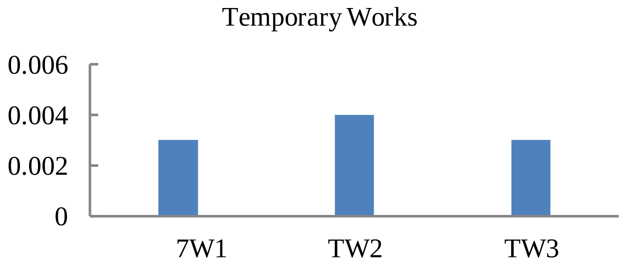

Figure 7. HEPs of Construction Subtask Category of Temporaryworks

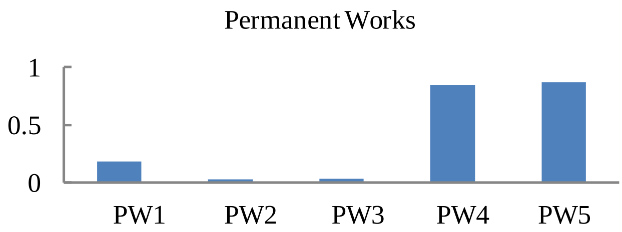

Figure 8. HEPs of Construction Subtask Category of Permanent Works

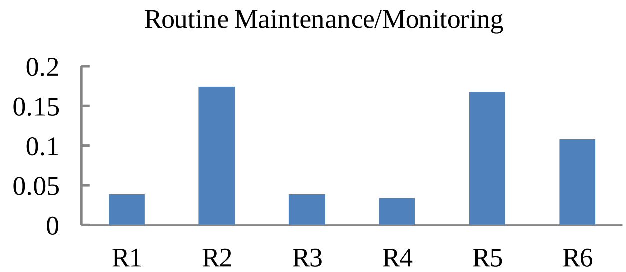

Figure 9. HEPs of Maintenance Subtask Category of Routine Monitoring

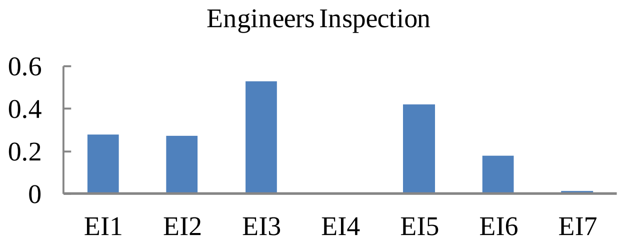

Figure 10. HEPs of Maintenance Subtask Category of Engineers Inspection

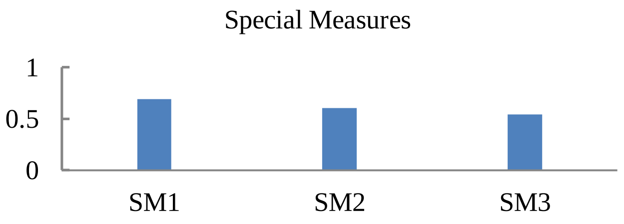

Figure 11. HEPs of Maintenance Subtask Category of Special Measures

VI. SUMMARY AND CONCLUDING REMARKS

With the help of HEART technique dominant error producing activity, leading to slope failure, have been identified. Remedial measures to overcome those errors producing condition responsible to enhance the human error also have been proposed. Since implementation of this technique heavily depends on expert opinion, the results also depend on the level of expertise and experience of the experts. This drawback can be replaced by a long term historical database of slope failure in the region.

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