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Finite Element Analysis on Shear Wall Panel Subjected to Blast Load

Solomon Abebe[1]

Abstract

Explosives require initiation for detonation to produce any explosive effects other than a fire and the initiated detonation wave rapidly converts the solid or liquid explosive materials into a very hot, dense, high-pressure gas. This paper investigates the dynamic response of a reinforced concrete framed building's shear wall prone to explosion and explosion effects. An explicit 3D nonlinear FEA packaged computational program ANSYS AUTODYN was used to simulate the explosion event. The efficiency of the FEA model was proven by comparing the numerical model results with experimental test obtained from recent literature. By varying explosive charge masses, scaled distances, reinforcing steel details, a parametric study was carried out by extracting the effective plastic strain and damage index values. FEA result revealed that for a given close-in explosion event, a decrease in scaled distance increases the effective plastic strain and damage index values. Moreover, for close-range scaled distances, reducing spacing of both longitudinal and transverse reinforcement bars at the possible locations of plastic hinges of the shear wall significantly minimizes the damages induced by the blast load.

Keywords: AUTODYN; Blast load; EBCS-EN; Finite element analysis; Scaled distance, Shear wall

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1. Introduction

Explosives require initiation for detonation to produce any explosive effects other than a fire and the initiated detonation wave rapidly converts the solid or liquid explosive materials into a very hot, dense, high-pressure gas, and the volume of the gas which had been the explosive material is then considered as the means of strong blast waves in air medium. One of the iconic features of explosion is that, only one-third of the total chemical energy available in most high explosives is released in the detonation process whereas the remaining two-thirds is released in slow manner in air medium as the detonation products mix with air and burn DOD (2007).

Likewise, conventional structures are susceptible to accidental loads and are more vulnerable to extensive damages. This is due to the reason that, those structures are designed and detailed to the magnitude of the design loads which are much lower than those produced by the abnormal high impulsive loads (impact and blast loads). Thus, designing and detailing civilian building structures that withstand such abnormal loads require immense researches on protective measurements such as unforeseen reinforcement detail provisions and shielding critical structural components by composite materials. (Abladey, 2014; Kyei, 2014; and Siba, 2014).

Shear walls as a critical vertical compressive structural member and less redundant when as compared to beams, slabs, are vulnerable to damages caused by explosion induced blast loads. Despite this fact, there are limited researches on shear walls under explosion effects and needs further exploration.

In this research, a finite element analysis (FEA) numerical technique using a computational program ANSYS AUTODYN was used to model and investigate the effects of explosion on shear walls designed and detailed in accordance with the Ethiopian Building Code of Standards (EBCS EN 1992-1-1_2013): Design of concrete structures. Furthermore, Hopkinson-Cranz approach and equivalent TNT were used for scaling the blast wave relationships. From the FEA post-processed data, the displacement-time history, effective plastic strain-time history, and damage index values were extracted and discussed.

2. Statement of Problem

Studies on explosions and their respective effects on shear wall panels are limited. The available analysis and design procedure manuals are prepared for only federal and military purpose buildings. Despite the experienced sever damages caused by explosions, many countries' buildings code of standard does not include this accidental loads. In addition to this, ways of designing and detailing civilian building components by use of different systems are not investigated in depth and requires further evaluation.

3. Objectives

The objectives of the research work reported in this paper are listed in the following sections.

3.1. General objective

The general objective of the study is to conduct a finite element analysis on shear wall panel subjected to blast load.

3.2. Specific objective

The specific objectives of the study are to:

- Investigate the effective plastic strain of shear walls when subjected to blast load.
- Evaluate the damage mitigation performance of different reinforcing steel arrangements of shear wall panels under blast induced shock waves.

4. Research Significance

Since accidental loads design guidelines for conventional buildings in Ethiopia are not included in the Country's code of practice (The Ethiopian Building Code of Standards), the study result from this finite element analysis can serve as an immense input for the policy makers and stakeholders by evaluating and revealing the effects of explosion on shear walls and respective damage mitigation techniques. Furthermore, this research work added a value to the study matter by further extending the research work performed by Kyei (2014), and Abladey (2014).

5. Methodology

In this study, among from the available numerical analysis techniques, the finite element analysis method of structural analysis which is a powerful tool for numerical solutions of a wide range of engineering problems is employed. In this method of structural analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements and an assembly process, considering the complex loads and constraints results in a set of equations which then gives an approximate behavior of the continuum can be easily addressed.

5.1. Finite Element Analysis

ANSYS AUTODYN software program, which is known by its typical features on explicit nonlinear finite element analyses was deployed for 3D model development, meshing, application of explosion, and subsequent FE analysis. Employed material models, blast loading application and FE procedures are presented in the following sections.

5.1.1. Material model

For material models, the Riedel-Heirmaier-Thoma (RHT) (after Riedel and Borrvall, 2011; and Hecttor and Sievers, 2017) concrete material model which is known by its typical features of compiled strain rate effects, equation of state (EOS), plasticity and three failure surface caps. Consequently, for reinforcement steel bar characterizations, the Jonson Cook strength material model known by its simplicity and account of the strain rate effects was employed. The equivalent TNT explosive was modeled by the well-known material model namely Jones-Wilkins-Lee (JWL) EOS (after Lee et al., 1973; and Seglets 2018).

5.1.2. Element model

For element model, the Lagrangian solid element was used to model concrete column and shear wall and sub structure. The solid element supports material and geometric non-linearity and has 8 nodes with three displacement, velocity, and acceleration DOFs per node in X, Y, and Z directions. Steel reinforcements were modeled using a two-node beam element. The element is compatible with concrete solid element and has three displacement, velocity, and acceleration DOFs per node in X, Y, and Z directions.

5.1.2.1. Modeling of concrete and reinforcing steel bars

Among from the available solid element types, Lagrangian element with 8 nodes was deployed to model the concrete part of the column and sub structure (The sub structure or base material was used in this study for sake of reflection of the blast induced shock waves. This base material was assumed to be made of concrete.). The strength along the compressive meridian is expressed as a triaxial compression normalized to the unconfined compression strength f_c in the AUTODYN solver in equation (1) Brannon and Leelavanichkul (2009).

$$Y^*_{TXC} = \frac{Y_{TXC}}{f_c} = a_1[\frac{p}{f_c} - \frac{p_{spall}}{f_c} r_f]^{a_2} \quad (1)$$

Where r_f =

$$\begin{cases} \left(\frac{\varepsilon'}{\varepsilon'_o}\right)^{\alpha} : p > f_c \; with \; \varepsilon'_o = 30 \square 10^{-6} s^{-1} \\ (\frac{\varepsilon'}{\varepsilon'_o})^{\beta} : p < f_c \; with \; \varepsilon'_o = 3 \square 10^{-6} s^{-1} \end{cases}$$

a_1 = Initial slope of failure surface,

a_2 = Pressure dependency of failure surface,

p_{spall} = Spall strength,

α and β = material constant.

5.1.2.2. Modeling of TNT explosive

The Jones-Wilkins-Lee (JWL) EOS that was determined to accurately describe the pressure-volume-energy behaviour of TNT explosion with different charge mass was deployed in the AUTODYN input parameters modelling steps. The employed JWL EOS has an equation depicted in equation (2) is referenced from Lee et al. (1973), and Segletes (2018).

$$p = A\left(1 - \frac{\omega}{R_1 V}\right) e^{-R_1 V} + B\left(1 - \frac{\omega}{R_1 V}\right) e^{-R_2 V} + \frac{\omega E}{V} \quad (2)$$

Where p is the pressure, v is the volume relative to the undetonated state ($\frac{v}{v_o}$). The parameters A, B, R_1, R_2 are constants fitting parameters associated with the model. While the parameter ω is an assumed-constant material property.

Keeping in mind the basic EOS coefficients in the AUTODYN solver GUI input module, different charge masses of TNT explosives were modeled in a 2D axially symmetric box and remapped onto the 3D numerical model. While having the density of the TNT explosive and masses, the volume of the mapped 3D box charge is obtained using the relationships explained in equation (3)

$$\rho = \frac{M}{V} \quad (3)$$

Where ρ and M is the density and mass of the TNT explosive material respectively.

5.1.3. Damage model

According to Brannon and Leelavanichkul (2009), once material begins to harden or soften, the damage factor D is used to determine the value of the current strength surface. The damage factor is defined using equation (4).

$$D = \Sigma \frac{\Delta \varepsilon^p}{\varepsilon^f} \quad (4)$$

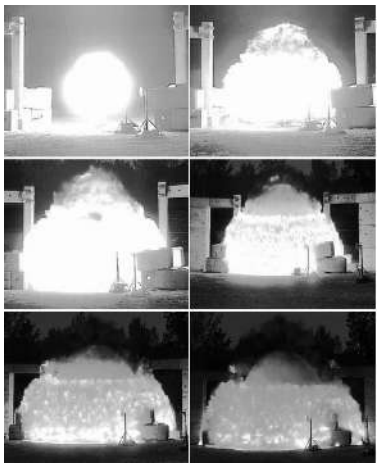
Where $\Delta \varepsilon^p$ is the accumulated plastic strain, and ε^f is the failure strain given by equation (5).

$$\varepsilon^f = D_1 (\frac{p}{f'_c} - \frac{p_{spall}}{f'_c})^{D_2} \quad (5)$$

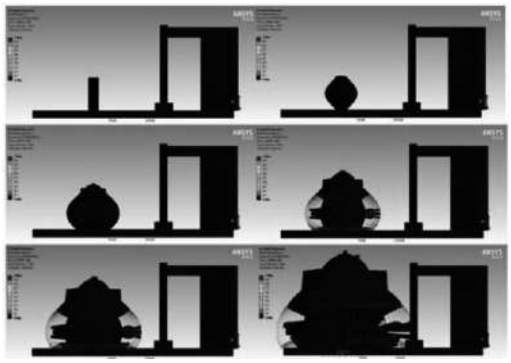
and parameter D_1 and D_2 are user input material constant. It is obvious that damage leads a reduction in stiffness hence the strength surface of a given strength model is modified by shifting the surface from an initial surface to a current damage one.

5.1.4. Validation

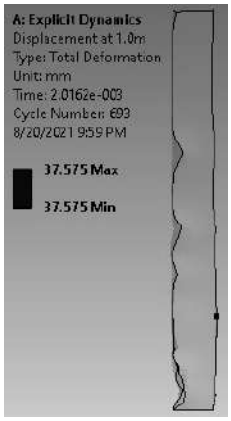
Field test result reported by (Siba, 2014) was used for validation finite element analysis. The specimen designated as CONV_10 has ALR value of 0.32, 300mm □ 300mm cross-sectional dimensions, 3200mm height and 41MPa concrete compressive strength. The column was reinforced with 4-25M and have 300mm tie spacing. Blast test was performed at 2.66m standoff distance with 150kg ANFO (123kg TNT) explosive material. Figure 1(a) shows field explosion test event of CONV_10 RC column whereas Figure 1(b) exhibited its corresponding FE developed model using ANSYS AUTODYN software program.



(a)



(b)



(c)

Figure 1: Blast wave propagation: (a) Field test (Siba, 2014); (b) FEA simulation (c) displacement value at lower one-third of a column height

From the finite element validation analysis, displacement was observed at lower one-third along the height of a column (Figure 1c). As compared to field test result, FE validation result exhibited 4.39% threshold value which is in the acceptable range.

6. Parametric Study

In the parametric study, a numerical investigation using a computational FEA program AUTODYN, on the performance of different shear walls with different reinforcement details on one-storey one-bay RC framed building when subjected to blast loads is presented. Figure 2 presents the locations of equivalent TNT explosives simulating different blast loading scenarios used in the parametric study. The parametric study results extracted from the FEA are the effective plastic strain and damage index values.

The parametric study comprised by three sections were accompanied by different blast scenarios respectively. To investigate the damage of different details of reinforced concrete shear walls, a 200kg, 400kg, and 600kg TNT charge masses located on outside of the building with 1.5m HOB and 3m SODs yielding a $0.51\frac{m}{kg^{\frac{1}{3}}}$, $0.41\frac{m}{kg^{\frac{1}{3}}}$, and $0.36\frac{m}{kg^{\frac{1}{3}}}$ scaled distances respectively were considered.

The 3-D frame had a 5m□5m planar area and to induce axial strain into the columns and shear walls, to simulate the real connection between beam, column, and shear wall. To account the static and dynamic reactions force from the beam reaction forces, the frame system was modeled as 3D FEA model. Consequently, to represent the loading system of the frame system, self-weight of each structural members (slab, beam, shear wall, column) was considered. In addition to this, to represent the functional use of the floor system, the slab was loaded with 8kN/m^2 as an imposed load (Figure 2).

Damage performance of such reinforced concrete shear walls can be studied by having different reinforcement detail provisions which was not studied in depth. Thus, to study the damage of different reinforcement details of reinforced concrete shear walls under near-field

explosion events, three shear wall reinforcement details were designed for the one-storey one-bay reinforced concrete framed structure. Figure 3 presents the reinforcement details for the three reinforcement details of shear wall typically SW_REINF_DET_#1, SW_REINF_DET_#2, SW_REINF_DET_#3 included in the parametric study. The design of the frame system was done in accordance with the Ethiopian Building Code Standard EBCS EN 1992-1-1: 2013_EBCS-2: Design of Concrete Structures. The shear walls had 150mm thickness reinforced with ϕ10mm longitudinal and transverse bars. The spacing between main bars of the three shear walls had different spacing. In other words, a reduced reinforcement bar spacings were employed at critical regions such as at the top and bottom points, left and sides, and mid points (see Figure 3).

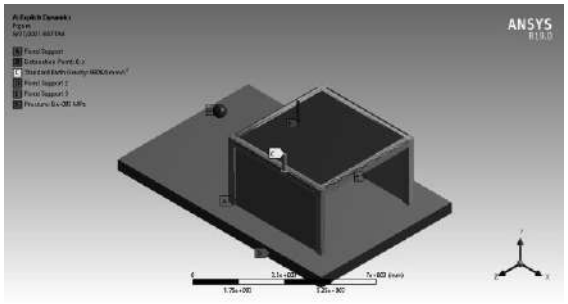
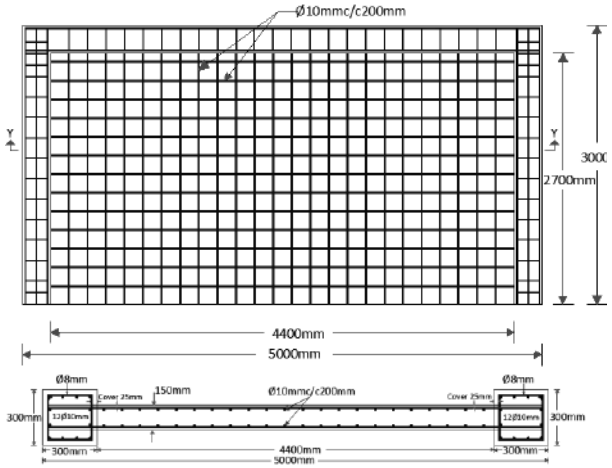
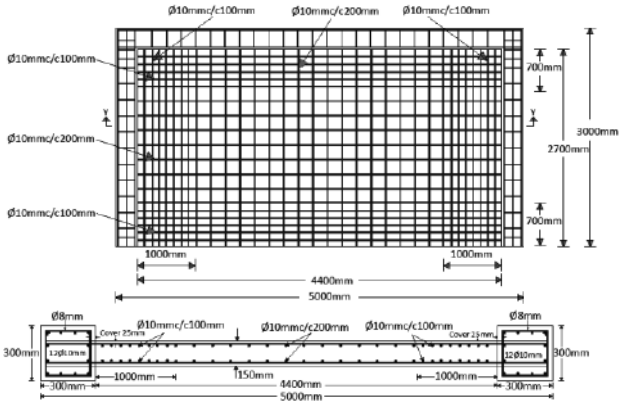


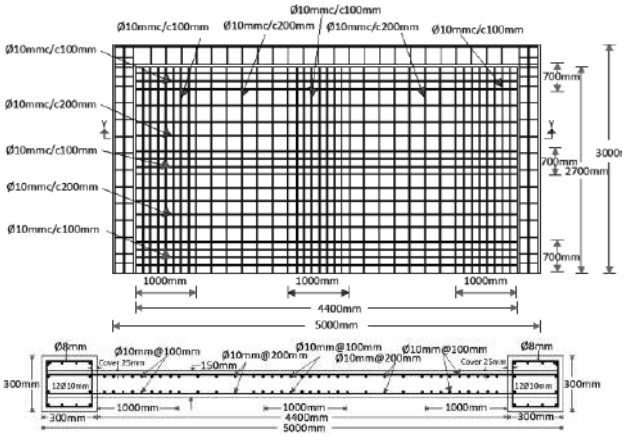
Figure 2: Finite element analysis model



(a)



(b)



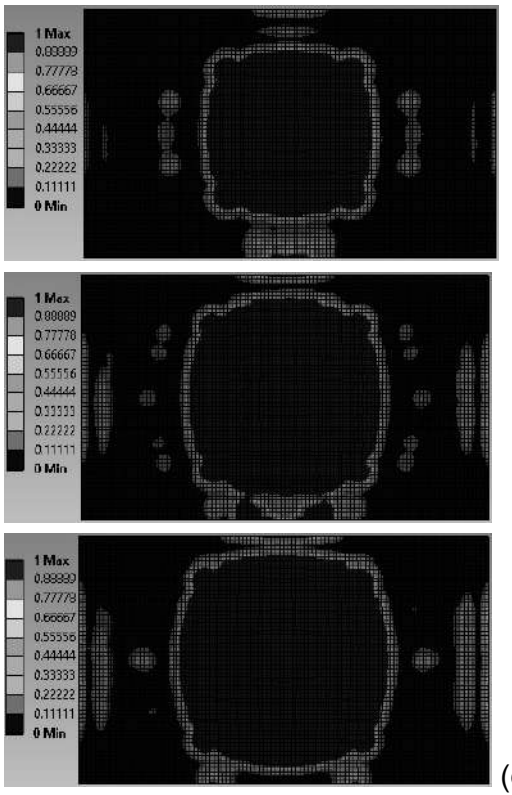
(c)

Figure 3: FEA models: (a) SW_DET_#1; (b) SW_DET_#2; and (c) SW_DET_#3;

7. Result and Discussions

To study the damage minimization performance of a reinforced concrete shear wall with different reinforcement details under blast induced shock waves, three reinforcement details for the whole frame system namely SW_REINF_DET_#1, SW_REINF_DET_#2, SW_REINF_DET_#3 are studied with three probable locations of explosives (close-range detonations).

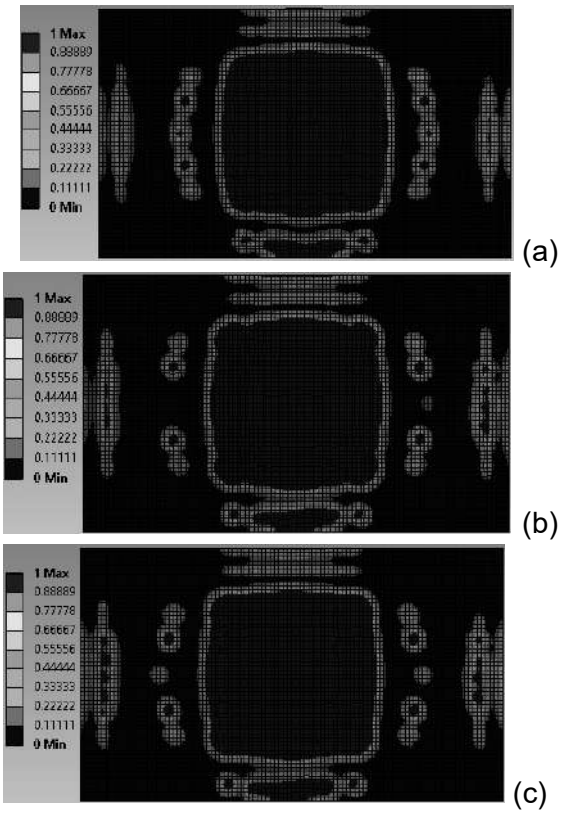
A numerical analysis result shows that, as the equivalent TNT explosive charge mass increase, the peak damage values also increase (Figure 4). A discussion on a sample analysis result for some of the scaled distance blast scenarios is presented in the following paragraphs.



(a) (b) (c)

Figure 4. Damage profile plots for SW_REINF_DET_#1 accompanied by 3m SOD with: a) 200kg; a) 400kg; and a) 600kg TNT explosive

Consequently, taking SW_REINF_#1 as a control shear wall detail scheme and comparing it with the remaining others, the numerical analysis result shows that, reducing the reinforcement spacings around the critical plastic hinge locations, i.e. end-points (SW_REINF_DET#2) and end-middle locations (SW_REINF_DET_#3) drops the damages induced by the close-range blast induced shock waves (Figure 5).



(a) (b) (c)

Figure 5. Damage profile plots for SW_REINF_DET_#1 accompanied by 3m SOD with: a) 200kg; a) 400kg; and a) 600kg TNT explosive

Figure 6 illustrates a damage index versus different close-range scaled distances for a reinforced concrete shear walls with different reinforcement detail schemes. From Figure 6, it is evident that, for a 0.36 $\frac{m}{kg^{\frac{1}{3}}}$ scaled distance, use of SW_REINF_DET_#2, SW_REINF_DET_#3 minimizes the peak damage values up to 4.23% and 10%. For a 0.41 $\frac{m}{kg^{\frac{1}{3}}}$ scaled distances a drop in peak displacement value up to 3.61% and 9.2% was obtained. Similarly, for 0.51 $\frac{m}{kg^{\frac{1}{3}}}$ scaled distances a 2% and 8% reduction in peak damage values were obtained.

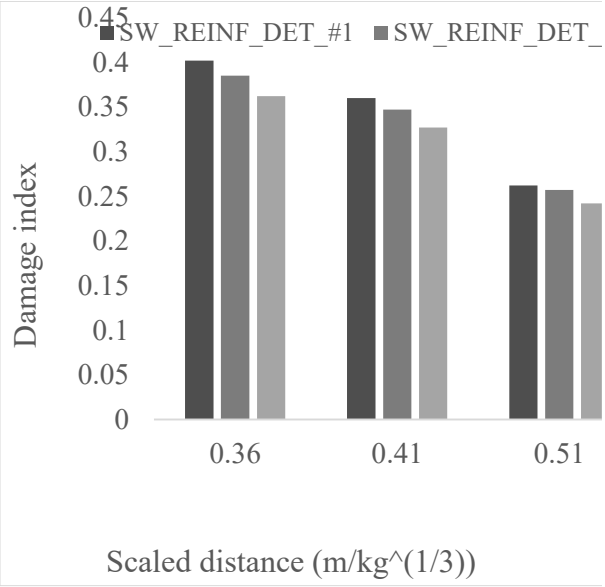


Figure 6: Damage index vs close-range scaled distance plot for RC shear walls with different reinforcement detailing schemes

Conclusions

Based on the results of the numerical study, the following conclusions are drawn.

- For an explosion event with different scaled distances, a decrease in scaled distance increases the peak effective plastic strain and damage index values and vice versa.
- Use of different reinforcement detailing provisions for a reinforced concrete shear wall is one system. Among from the available reinforcement detailing schemes, reducing spacing of both longitudinal and transverse reinforcement bars at the possible locations of plastic hinges helps to withstands damages induced by the blast induced shock waves. Especially, in this study, SW_REINF_DET_#3 significantly minimizes the peak damage indices for a close-in range explosion.

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Building Response Analysis for a Tunnel in Escarpment Seismic zone of Ethiopia

Wondemagegne Aseffa [1] and Henok F. Gebregziabher[2]

Abstract

This study is concerned with tunnel induced ground surface settlement under seismic actions using PLAXIS 2D V 8.6 Finite Element software with plane strain modeling concepts. Practical construction phases were adopted during the numerical analyses to simulate the actual conditions on site, including the seismic effects expected in the study area, Karakore. Comparison of the results of the different phases indicates that the invert excavation and lining phase gives the maximum ground surface vertical settlement of 85 mm.

The outputs of the numerical analyses have further been taken as inputs for the building damage analysis using the Limiting Tensile Strain Method (LTSM) to categorize buildings' damage extent above the tunnel on the ground surface. The building response analyzed using LTSM confirms that the damage extent associated with maximum vertical settlement is found to be within the allowable limits; the one associated with relative settlement of the building edges is categorized as negligible and that associated with relative rotation is categorized as slight.

Keywords: *Building response analysis, Seismic effect, LTSM, NATM, Building damage category, 2D Finite element method.*

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1. Introduction

Awash-Kombolcha-Haragebeya Railway Project is among the recent railway projects in Ethiopia. The design and construction of this project was undertaken by Yapi Merkezi, a Turkish Contractor. The tunnel T-04 is one among the railway tunnels of the project that has been constructed in the seismic prone areas of Karakore (Figure 1), whose location is given by the geographical coordinates between 1132687N-1132814N and 609159 E- 608979E [1].



Figure-1: Tunnel T04 (south portal view)

The consequences of earthquakes on tunnels include both transient and permanent ground deformations. Transient deformations cause small strains [2]. For seismic hazard analysis, historical earthquake data, earthquake source characteristics and attenuation relationships are all significant elements [3].

The probabilistic method considers recurrence laws for any earthquake magnitude greater than 5 and sums up the contribution of all conceivable earthquakes that can influence a site. As a result, the likelihood of exceeding every value of a parameter of predicted soil movement at the location over a certain time period is calculated [3].

In seismic prone areas, tunnels are subjected to both static and seismic loading conditions. Under such actions, ground subsidence will be induced; which in-turn affects the existing surface and subsurface structures. Predicting tunnel induced deformations of such structures and assessing the risk of damage is an essential part of planning, design and construction of tunnels in an urban environment [4]. The widely used design approach to predict and assess potential building damage due to ground deformations is the Limiting Tensile

Strain Method (LTSM). This method doesn't account for the soil-structure interaction and the building is modeled as an elastic beam subjected to imposed greenfield settlements and the induced tensile strains are compared with limiting values from the literature.

The construction of tunnels in soft ground inevitably causes ground movement or settlement in an urban environment; this settlement in turn can affect existing surface or subsurface structures [5]. The effect of the tunnel under the current research in the study area on the buildings above it have been investigated previously by considering static loads only [6]. However, the seismicity of the area calls for dynamic analyses, which is addressed in the current study.
[7] performed Probabilistic Seismic Hazard Analysis (PSHA) to obtain the ground motion shaking intensity of the study area with the purpose of analyzing the adequacy of the designed section against dynamic loads on the tunnel. The expected seismic loads have been adopted from that research and incorporated in the current study for analyzing the expected damage levels of buildings on the ground surface under which the tunnel at Karakore is constructed.

2. Numerical Modeling and Analysis

The standard fixities of PLAXIS with full fixity at the geometry's base and roller conditions on the vertical sides (U_x = 0 and U_y = free) has been applied throughout the computations. The dynamic analysis requires additional boundary condition which incorporates the standard earthquake absorbent boundary and it is used at the bottom, right and left sides of the boundaries. The absorbent boundary is kept far away in comparison to the standard static boundary condition in order to absorb the increments of stresses caused by the dynamic loads; that would otherwise be reflected inside the soil body.

The numerical analysis of the tunnel has been performed using PLAXIS 2D [8] with plane strain modeling considerations since the tunnel is very long in relation to the transversal dimensions. The 15-noded triangular element type is utilized to generate the finite element mesh. The analysis is limited to pseudo static loads with application of harmonic loads, due to the absence of previous earthquake event time history records.

The finite element modeling suits the simulation of the actual construction stages of the NATM (New Austrian Tunneling Method) procedure that was employed in-situ. The analysis of the construction sequences were performed by using the plastic analysis type with the loading input for the static calculation followed by the dynamic analysis type. The following six loading phases are basically used in the finite element modeling:

I. Installation of pipe umbrella
II. Top heading excavation and lining
III. Bench anchor or rock bolt activation
IV. Bench excavation and lining
V. Invert excavation and lining
VI. Seismic loading

Linear elastic properties were used for modeling the lining while the Mohr-Coulomb constitutive model was employed for the soil layers. Geotechnical parameters have been adopted from the geotechnical report provided by the Contractor, Yapi Merkezi [9]. The material parameters of equivalent soil cluster were used at the crown, to account for the stiffness of the pipe umbrella

in the two dimensional analysis; which is determined by converting to equivalent values of the parameters based on the proportions of the soil and umbrella cross sections. The material parameters used in the numerical modeling are presented in Table 1.

Table 1 Model parameters.

Description	Parameters	Magnitude
Simplified Umbrella	Young's Modulus E_{ref} [kPa]	2,324,000
	Unit weight ɣ [kN/m^3]	24
	Cohesion c [kPa]	100
	Friction angle ϕ_u [^{o}]	40
	Poisson's ratio v [-]	0.25
Lining	Axial stiffness [MN/m]	15500
	Flexural Stiffness [MN/m^2/m]	323
	Poisson's ratio v [-]	0.2
	Self-Weight [kN/m/m]	12.5
	Modulus of elasticity E_c [GPa]	31
	Thickness [m]	0.5
Soil layer1	Unit weight ɣ [kN/m^3]	20
	Cohesion C_u [kPa]	10
	Friction angle ϕ_u [^{o}]	32
	Modulus of Elasticity, E [kPa]	35000
	Poisson's ratio v [-]	0.4
Soil layer 2	Unit weight ɣ [kN/m^3]	10
	Cohesion C_u [kPa]	20
	Friction angle ϕ_u [^{o}]	35
	Modulus of Elasticity, E [kPa]	50000
	Poisson's ratio v [-]	0.4

3. Results and discussions

3.1 Major results of the numerical analyses

According to the results of the numerical analyses, the last construction phase, i.e., the invert excavation & lining phase as well as the dynamic loading phase are found to give more critical results than other phases. The vertical displacement plots obtained during the two phases and are later used in the determination of the expected damage level of buildings on the surface are presented in Figures 2 and 3.

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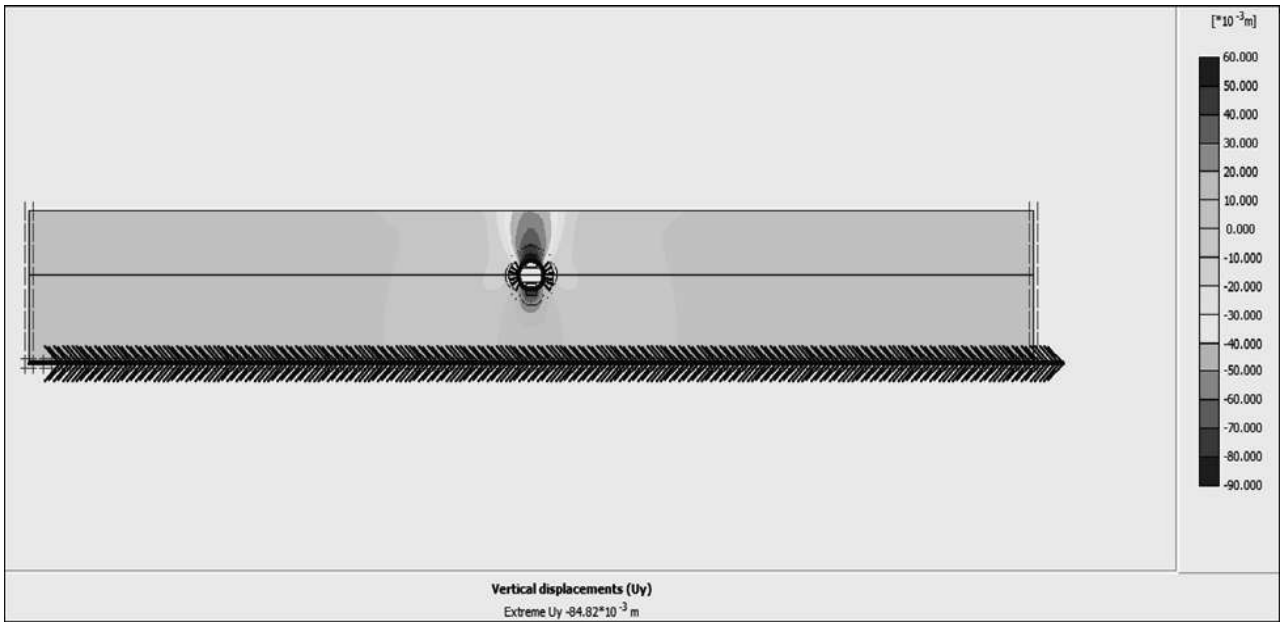


Figure-2: Vertical displacement plot for invert excavation and lining phase

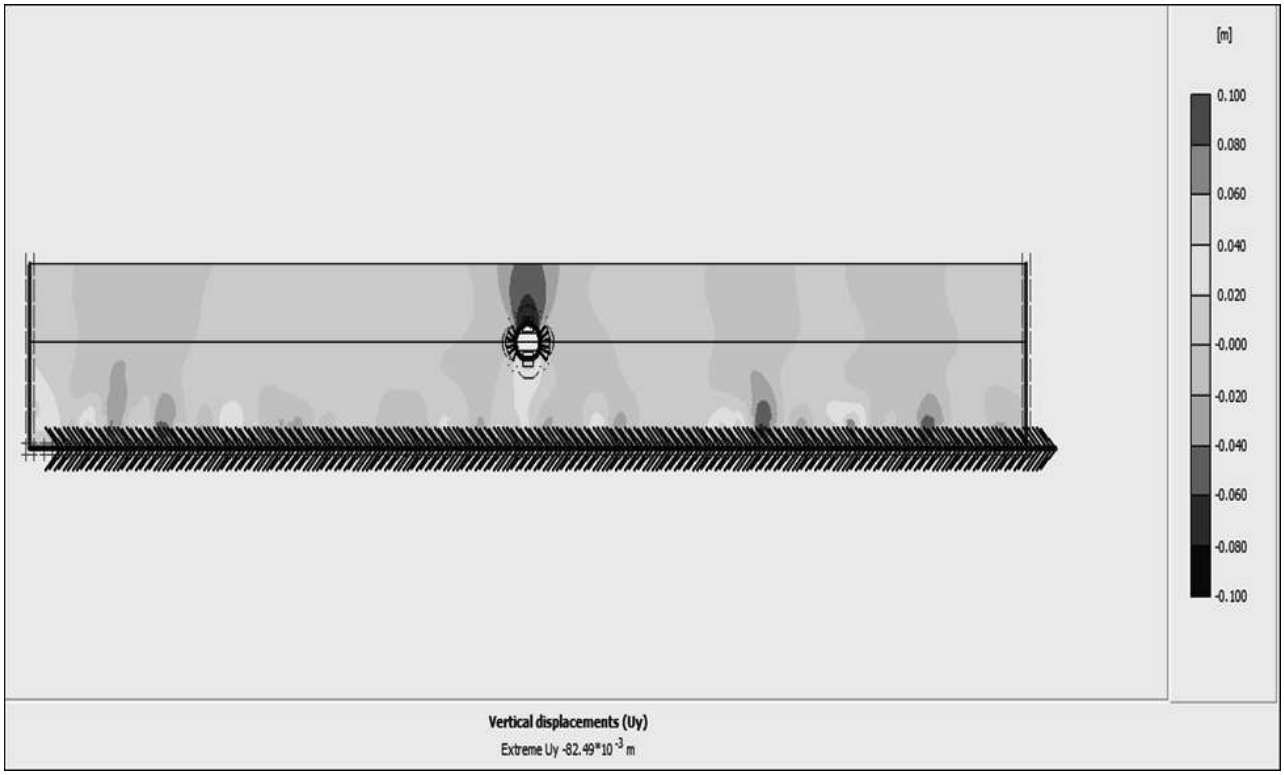


Figure-3: Vertical displacement plot for the seismic loading effect phase

The vertical downward tunnel induced surface settlement $S_{v.max}$, of the invert excavation and lining phase was found to be slightly larger than the dynamic loading phase; the computed values being 85 mm and 82.5 mm for the respective phases. These results are used for assessing the expected damage levels of existing buildings on the surface, using the LTSM.

3.2 Categorizing the Building Damage Level

There are existing houses above the tunnel within the tunnel trough width zone, W. A house of 12 m length, L, situated just above the tunnel centerline (TC) was considered for the damage assessment (see Figure-4). While its 3 m length is located to left of the tunnel centerline, the remaining 9 m falls on the right side of the tunnel (Figure -5).

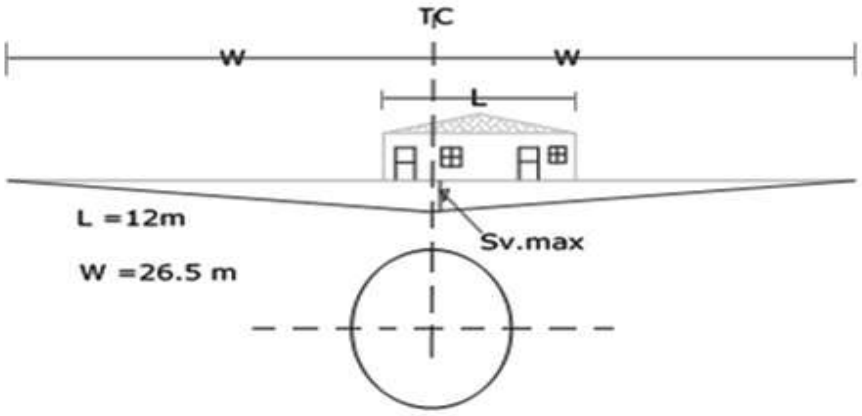


Figure-4. Arrangement of existing house relative to tunnel induced settlement trough

The results obtained from the governing undrained analysis were used for the determination of parameters that are used in categorizing the building damage. The damage risk evaluations of the building in this investigation have been carried out according to LTSM using the three deformation parameters; namely, maximum vertical settlement ($S_{v,max}$), differential or relative settlement (δ_{Sv}) and relative rotation or angular distortion (β).

The settlement at the left and right side of the building edge are 45.7 mm, and 33 mm respectively, giving rise to a relative settlement δ_{Sv}, of 13 mm.

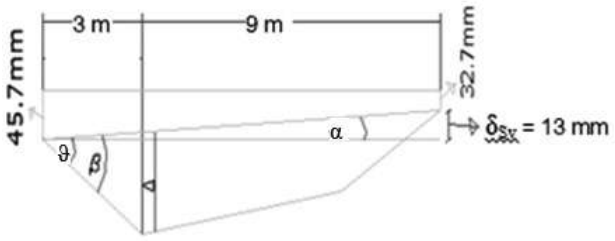


Figure-5: Configuration of displacement parameters for the undranied condition

The average settlement slope, ϑ, can be calculated by projecting a straight line from the point of maximum settlement, which is at the center of the tunnel to the point of settlement trough beyond which the settlement from the ground surface is less than 1 mm or negligible.

$\tan\vartheta = \frac{S_{vmax}}{W}$ = 1:320.

The relative strain α is calculated as $tan \propto = \frac{\delta_{Sv}}{L}$ = 1:923.

The angle of distortion β is finally determined as the sum of the average slope ϑ and the relative strain α; which is equivalent to tan β = 1:238.

Based on these computed parameters, the building damage is categorized as illustrated in Table 2 with reference to CUR 162 [10] and Eurocode 7 [11].

Table-2 Damage category according to CUR 162 and Euro code 7

Deformation Parameters	Limit Val. (mm)	Source of limit	Calculated Result	Interpretation
Max. vertical settlement	<150	Council on Undergraduate Research, CUR162	82.5	Safe
Relative settlement	<1:150	Euro Code 7	1:923	Safe
Relative rotation	< 1:300	Council on Undergraduate Research, CUR162	1:238	Unsafe

While the maximum vertical and relative settlements are within the tolerable limits, the relative rotation criteria set by CUR162 has been exceeded. The expected building damage levels related to the calculated deformation parameters are presented in Table-3.

Table-3 Category of building damage level

Deformation Parameter	Source of Limit	Damage Category
Relative settlement (1:923)	Council on Undergraduate Research, 162	Negligible
Relative Rotation (1:238)	Skempton & McDonald [12]	Slight
	Bjerrum [13]	Tilting will be expected

Even though the damage levels according to the standards are negligible and slight, the possibility of higher damage levels on larger structures that will be built above the tunnel exists and detailed building response analyses for such structures are mandatory.

4. Conclusions

The present study focused on investigating the damage level of buildings on the seismic active city of Karakore due to a recently constructed railway tunnel underneath. After determining the dynamic loads based on previous researches, the tunnel induced settlement at the ground surface under seismic action was analyzed by using FEM. Undrained case was considered being more relevant than the drained case to evaluate the building response analysis under seismic action.

The numerical analyses indicated that the tunnel induced ground surface vertical settlement for the case of invert excavation and lining phase was found to be slightly larger than that of the seismic effect phase and thus considered for the worst case building damage analyses.

The expected building damage was analyzed by using Limiting Tensile Strain Method (LTSM) considering existing houses above the tunnel. The damage assessment was based on three deformation parameters; i.e., vertical settlement, relative settlement and relative rotation/angular distortion that have been computed using the numerically analyzed tunnel induced settlement profile at the ground surface. The damage extent associated with maximum vertical settlement is found to be within the allowable limit (150 mm) while the one associated with relative settlement of the building edges is categorized as negligible. Slight damage of the building considered for the analysis will be expected with regards to the relative rotation (angular distortion).

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POTENTIAL FACTORS AFFECTING E-TENDERING APPLICABILITY FOR THE PROCUREMENT OF ETHIOPIAN FEDERAL ROAD CONSTRUCTION PROJECTS

[1]Hilina Belachew, [2]Denamo Addissie

ABSTRACT

Bidding practice which is one of the steps in procurement is identified as one of the major short coming of the Ethiopian construction industry. The fact that the current Ethiopian construction tendering practice is paper-based has a number of drawbacks like human errors in document production, poor audit trail, access problems, security concerns, insufficient copies, and time-consuming being the major ones. A number of studies shows that the challenges of a paper-based tendering can be improved via e-tendering implementation. This paper presents the result of a literature survey, interview, and questionnaire survey conducted to identify the various factors affecting e-tendering applicability in Ethiopian road construction projects. It identified a number of relevant variables under Critical Success Factors (CSFs) and barriers, and presents a model for future research studies. First, the perception and experience of tendering professionals involved in Ethiopian road construction projects was assessed via questionnaire and interview survey. Selected e-tendering practitioners from Non-Government Organizations (NGOs) were also interviewed on their experience while implementing the system. Accordingly, the result showed that reliability of information communication & technology, top management support & employee commitment, reliability of users' acceptance, reliability of legal factors, and reliability of monitoring & evaluation system would positively affect e-tendering implementation and the same were considered as a CSF. Similarly, a number of factors related to management, organization, environment, and technology may hinder the implementation of the system, hence taken as a barrier to e-tendering implementation.

Key words: Construction; e-tendering; Road Construction Projects; Critical Success Factors (CSFs); Barriers

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1. Introduction

In the construction industry, the introduction of e-tendering has resulted in positive outcomes. However, there is still a learning curve and barriers exist for successful adaption. According to Rankin et al. (2006) investigated drivers and barriers of Electronic Procurement (EP) in Canadian construction industry. Accordingly, the study confirmed that the list of drivers and barriers identified from the procurement of goods and services in other industries apply to the construction industry. However, Eadie et al. (2007) asserted that due to the greater complexity and nature of the construction industry, the barriers to construction EP could be performing differently to the general goods and services industry. This study adopts the four classification[1] of Tran et al. (2011) in identifying the barriers & challenges of EP implementation in the Ethiopian construction industry; technology, management, organization, and environment as this classification was used by different scholars; (Amarapathy et al., 2013; Costa *et al.*, 2013; Davila *et al.*, 2003; Eadie *et al.*, 2007; Eadie et al., 2007; Hilmi et al., 2019; Lavelle and Bardon, 2009; Rankin et al., 2006; Sitar, 2011; Tatsis et al., 2006). Hence, to avoid redundancy & due to the holistic nature of Tran et al. (2011) and Shukla et al. (2016) classification, the study used the same categories of challenges & barriers, as tabulated under Table 1.

Table 1 Barriers & challenges to EP implementation in the construction industry
Source: Adapted from (Shukla et al., 2016; Tran *et al.*, 2011)

Perspective	Barriers/Challenges	References
Technology	Lack of system integration[2]; standardization & compatibility issues (higher investment costs in compatible system)	(Costa et al., 2013; Davila et al., 2003; Rankin et al., 2006; Sitar, 2011; Zou and Seo, 2005)
	Insufficient assessment of systems before installation	(Sitar, 2011; Weigel and Ruecker, 2017)
	Security concern (security threat or security of transaction & uncertainty i.e., data integrity and confidentiality violation)	(Amarapathy et al., 2013; Eadie et al., 2007; Hilmi et al., 2019; Lavelle and Bardon, 2009; Rankin et al., 2006; Sitar, 2011; Tatsis et al., 2006)
Management	Resistance to change (at managerial level)	(Amarapathy et al., 2013; Costa et al., 2013; Davila et al., 2003; Eadie et al., 2010; Hilmi et al., 2019; Sitar, 2011)
	Development of confidence to use new technology	(Eadie et al., 2007; Rankin et al., 2006; Zou and Seo, 2005)
	Lack of leadership or upper management support	(Amarapathy et al., 2013; Eadie et al., 2007; Weigel and Ruecker, 2017)
	Higher cost of investment, the challenge in finding an affordable technical solution, expensive & complex nature of e-signature	(Costa et al., 2013; Davila et al., 2003; Eadie et al., 2007; Rankin et al., 2006; Sitar, 2011)
	Lack of skilled personnel & technical expertise, and lack of training	(Amarapathy et al., 2013; Costa et al., 2013; Eadie et al., 2007; Sitar, 2011)

[1] The same classification and/or sub-categories for challenges/barriers of EP implementation was mentioned and used in different scholars; (Amarapathy et al., 2013; Costa *et al.*, 2013; Davila *et al.*, 2003; Eadie *et al.*, 2007; Eadie et al., 2007; Hilmi et al., 2019; Lavelle and Bardon, 2009; Rankin et al., 2006; Sitar, 2011; Tatsis et al., 2006). Hence, to avoid redundancy & due to the holistic nature of Tran et al. (2011) and Shukla et al. (2016) classification, the study used the same categories of challenges & barriers.

[2] Interoperability & integration with other systems or system-to-system within & between organizations.

Perspective	Barriers/Challenges	References
Organization	Lack of resources, different organizational structure, company access to internet	(Sitar, 2011; Zou and Seo, 2005);
	Challenge in shifting the mindset of people (Magnitude of change)	(Rankin et al., 2006; Stewart et al., 2003; Sitar, 2011; Weigel and Ruecker, 2017)
	Staff turnover	(Hilmi et al., 2019; Weigel and Ruecker, 2017; Zou and Seo, 2005)
Environment	Inadequate technological infrastructure, Lack of national IT policy related to EP	(Stewart et al., 2003)
	Lack of an effective legal and regulation system, lack of system standards[3]	(Amarapathy et al., 2013; Costa et al., 2013; Stewart et al., 2003)
	Lack of demand from customers/clients, lack of corporate executive-level support	(Zou and Seo, 2005)
	Lack of marketplace & suppliers' readiness, a "wait-and-attitude" among firms	(Tran et al., 2011)

[3] Due to the availability of an excessive number of e-platform.

After carefully identifying potential barriers and challenges, there is a need to determine the CSFs that are likely to influence the success of e-tendering initiatives in the construction tendering process of the public sector. This study considers five CSFs identified by Tebeka and Yessuf (2019) extracted from existing works of literature to avoid redundancy (see Table 2).

Table 2 CSFs for successful implementation of e-tendering
Source: Adopted from (Tebeka and Yessuf, 2019)

Perspective	CSFs	References
Top management support & employees' commitment	Staff training & capacity building; provision of adequate resource (financial, material, and human resources); employee's commitment; the skill of procurement employees with IT perspective; E-tendering implementation strategy	(Boonstra, 2013; Costa et al., 2013; Mohammed, 2013; Shukla et al., 2016; Tebeka and Yessuf, 2019; Vaidya et al., 2006)
Information Technology & infrastructure	Consistency of internet connection; availability of reliable ICT infrastructure within an organization; compatibility of existing hardware & software with the e-tendering implementation system; functional integration of the e-tendering system with other business processes; Security & authentication measures	(Ahimbisibwe,2018; Becker, 2018; Shukla et al., 2016;Tebeka and Yessuf, 2019)
Legal factors	Availability of legal framework; availability of e-tendering operation instructions & manual; availability of legal & administrative procedures	(Becker, 2018; Tebeka and Yessuf, 2019)
Users' (buyers & suppliers) acceptance	Trust of buyers & suppliers on the system; willingness of users; provision of training	(Ahimbisibwe, 2018; Vaidya et al., 2006; Tebeka and Yessuf, 2019)
Reliability of monitoring & evaluation system	Existence of a project management team to monitor & evaluate the progress of its implementation; continuous performance evaluation & feedback; compliance with rules & regulations is ensured; checking procurement guidelines are practiced & monitored	(Tebeka and Yessuf, 2019; Vaidya et al., 2006)

Regarding the practice of EP in Ethiopia, currently, the public organization mandated to lead EP initiative in Ethiopia is the Federal Public Procurement & Property Administration Agency (FPPPAA) and is working in coordination and collaboration with the Ministry of Finance and Economic Cooperation (MoFEC) and Ministry Communication and Information Technology (MCIT) as well as other stakeholders ((Federal Public Procurement and Property Administration Agency), 2018). Similarly, a

strategy document and a roadmap (which covers five years from 2018-2023 G.C) have been developed to guide the introduction of the electronic Government Procurement (e-GP) system. About the already existing EP system in the country, Kumar (2018) revealed that MCIT and Bahir Dar University (BDU) are already using EP system.

2. Problem statement and research objectives

Bid procurement practice, as per Ayalew et al., (2016) was identified as one of the major shortcoming of the Ethiopian construction industry. Even if the objectives of public procurement in the construction sector can be achieved through the traditional paper-based tendering, it has many inherent limitations (Emiru, 2015). To this, Elias *et al.* (2005), Berhanu, (2019) assert the following drawbacks; high processing cost, time-consuming and slow process due to human errors & manual procedures, high paper usage and storage, restricted mobility or highly dependent on geographical location of bidders. Telgen and Ambaw (2017) state that the current construction procurement approach is characterized by high corruption[4] prevalence. Accordingly, lack of accountability in the public procurement system contributes significantly to opening opportunities for corruption. In relation to this, delays in some of the assessed Ethiopian Roads Authority's (ERA's) projects[5] implementation has occurred due to procurement related factors. Accordingly; poor quality of bidding and/or design document production, problem in internal coordination to finalize paper-intensive bidding documents, inadequate technical information availability[6] , lengthy bid evaluation and selection process, time-consuming bidding procedure, and poor response[7] from bidders are mentioned as challenges and problems in the current tendering practice ((Transport and Digital Development Global Practice), 2018; (Transport and ICT Global Practice Country department AFCE3), 2015).

Despite the criticality of public procurement as a government function, it has been a neglected area of academic education and research (Vaidya et al*.,* 2006). Hence, Vaidya et al. (2006) argue that EP has been identified as a priority agenda and many governments have implemented or are in the process of implementing an EP system. As a relatively new topic in the e-construction arena, many organizations need guidance and advice to proceed with this new technology (Vaidya et al., 2006). Without a set of potential factors, it seems impossible to trace the progress and success of its implementation. Thus, based on the foregoing research problem, this study aimed at investigating the various factors affecting the suitability/applicability of e-tendering by taking the procurement of Ethiopian federal road construction projects as case study.

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[4] Corruption is a major issue in the public procurement system of developing countries and it's estimated that countries annually lose 20%-25% through their public spending through malfunction of officials and Ethiopia is no exception to this statement (Telgen and Ambaw, 2017). In relation to this, the tender evaluation may become biased, unfair, and dishonest due to unprofessional or unethical procurement committees (Kusumarukmi and Adi, 2019). Similarly, the leak of the lowest bid price is another problem to be considered in a paper-based procurement or tendering.

[5] Although the assessed projects were very small in number when compared to the overall ERA projects, the need for the update of the procurement procedures was already indicated in the project completion report.

[6] Such inadequacy of information leads to several rounds of clarifications requested by bidders, which makes the process lengthy. A summary of the borrower's project completion report was prepared for the World Bank financed Road Sector Development Stage III projects (Adaptable Program Lending; APL) in 2015 and it, assert that, on average it took 13 and 24 months to award works and supervision consultant service contract respectively, resulting in further challenges as exhibited during implementation such as staff substitution.

[7] According to the completion report for projects under APL4 one project was bid twice due to poor response during the first bidding process (Transport and Digital Development Global Practice) (2018).

3. Methodological approach

A research methodology is a generic term used for the process of defining problems, gathering facts or data, analyzing data, and accomplishing objectives (Patel, 2017). It is a systematic way of solving a problem (Kothari, 2004). Due to the nature of the research, both a quantitative and qualitative research methodological approach was adopted. Accordingly, questionnaire survey and interview were conducted involving professionals engaged in the tendering phase to assess the potential factors affecting e-tendering applicability. Both primary and secondary data sources were used for this particular study. The primary data was predominantly collected through a semi-structured interview and questionnaire survey. The exhaustive literature reviewed on the subject area was the major secondary source of data. Sources of literature were books, journal articles, conference proceedings, academic reports, etc.

For the survey research sampling, the nature of the research necessitated the use of a non-probabilistic approach. The bounding criterion adopted to select respondents were professionals area of operation (working for client, contractors & consultants involved in road construction), relevant experience (who participated in the tendering phase of the Ethiopian Roads Authority (ERA) for a minimum of five & six years for questionnaire & interview survey respectively), and educational background of professionals (professionals holding a minimum of Bachelor of Science Degree & above in construction related Engineering field). Based on the above-defined potential participants, it had been articulated that the ideal way for getting access to professionals involved in the tendering process of Ethiopia's Federal road construction projects were using snowball sampling[8] approach, while for the semi-structured interview data collection**,** the concept of data saturation[9] was used to determine the appropriate sample size.

4. Data analysis

The study employed both content & thematic analysis to analyze the data obtained through interviews and document reviews. The analysis of textual data and/or interview transcripts was computed using the most widely used qualitative data analysis program, QSR NUD*IST (Non-numerical Unstructured Data Indexing Searching and Theorizing) Vivo 10, also called NVivo[10].

To analyze the data obtained from the survey questionnaire, the most widely used statistical analysis software package i.e., *Statistical Package for Social Science (SPSS)* was used. The software was used to conduct descriptive statistics, reliability test, and check the validity of the instrument. In addition, Relative Importance Index (RII) was calculated on respondents' perception during the questionnaire survey regarding the potential factors affecting e-tendering applicability in the study area. The calculation for RII determines the relative

[8] Snowball sampling also known as chain referral method. It is a well-known non-probability method of survey sample selection that is commonly used to locate hidden or hard to find population and useful to approach dispersed/small population. It's commonly considered as a purposeful method of data collection in qualitative study (Naderifar et al., 2017).

[9] Data saturation is the point in which new data tend to be redundant of data already collected. It is used in qualitative research as a criterion for discontinuing data collection and/or analysis. When similar instances or themes are seen over and over again, the researcher can be confident that a category is saturated (Baker et al., 2018).

[10] NUD*IST, NVivo has features like character-based coding, rich text capabilities, and multi-media functions that are crucial for qualitative data management (Toma et al., 1972). Moreover, the strength of the software lies in its high compatibility to research designs, data analysis methods, and its ability to accommodate a number of different types of data (Toma, Ollman and Roberts, 1972; Dollah et al., 2017).

ranking of factors and indicates how much the one factor is more important than the next.

5. Result and discussion

CSFs of e-tendering implementation

Based on a systematic literature review, 21 CSFs for e-tendering application in the construction sector were identified. The study asked respondents (including clients, contractors, and consultants) to rank the factors based on their understanding and perception on the relative contribution of the factors for the successful implementation of e-tendering. Accordingly, the top three factors are discussed underneath;

Consistency of internet connection: Ranked first with an RII value of .967. Research conducted by Tebeka and Yessuf (2019), asserted that consistency of internet connection is a crucial component for the full implementation of EP system for public procurement.

Availability of reliable ICT infrastructure within an organization: Ranked second (RII=0.949) is the reliability of information technology and infrastructure-related factor. According to respondents, the lack of a reliable ICT infrastructure in an organization can be a challenging factor while implementing e-tendering. Provision of ICT infrastructure was mentioned as one of the five categories described by Boonstra (2013), where top management support is provided for the success of any information system project success. Thus, ICT infrastructure within an organization falls under this category. Naveed Sarwar 2017 (cited in Tebeka and Yessuf (2019)) found the availability of ICT infrastructures as one of the top three CSFs for EP adoption in Pakistan public organizations.

3. Staff training: third-rated CSF with RII=0.947. The finding is consistent with research conducted by Islam and Zhu (2012) whereby adequate training of employees to enable them to take advantage of the new system is one of the three CSFs identified in the study. Similarly, Becker (2018) claims awareness-raising actions and extensive training programs to be the basic success factors for Estonia's e-government system.

NVivo generated the node model as shown under Appendix 2 to identify various nodes (relating to CSFs affecting e-tendering implementation) in the interview responses. The figure shows pictorial representations of the CSFs affecting the success of e-tendering implementation. NVivo generated this model automatically by linking the various CSFs mentioned and discussed during the interview. It shows the identified patterns of themes from the interview transcript. (See Appendix 2).

Barriers of e-tendering implementation

Primarily,16 factors under four basic categories or groups were identified as barriers & challenges from literature review. Then, respondents ranked these factors based on their understanding and perception of the concept. Accordingly, the top three ranked barriers are discussed underneath;

1. Lack of system integration (RII=0.895): was ranked first among the respondents of the questionnaire survey. The finding was consistent with a study conducted by Nesan Lenin (2011), whereby a lack of integration of new tools with the already existing process is one of the concerns & uncertainties why contractors became too reluctant to experience e-tendering. Such lack of system integration standardization and compatibility issues are mentioned as a challenge to EP implementation in the

construction industry by a number of authors; (Costa, Arantes and Valadares Tavares, 2013; Davila et al., 2003; Rankin et al., 2006; Zou and Seo, 2005).

2. Lack of training/ capacity-building programs (RII=0.879): was ranked second during the questionnaire survey. Due to a lack of inadequate insight into how e-tendering works, users usually hesitate to use e-tendering. Another informant reiterated;

> *"…working on the mindset of users is very crucial. To do so, constant training or capacity building program must be given to users." Team Leader Engineering Procurement Directorate from representative Employer's Government office.*

3. Challenge in shifting the mind-set of users (RII=0.86): was ranked third during the questionnaire survey and it was one of the most frequently referenced barriers during the interview. Considering the "newness" of e-tendering practice among users, it turns out some users may be refrained from implementing it. With this regard, one practitioner of the system put it as follows; *"I think the biggest challenge while implementing e-tendering is raising the awareness of users, and suppliers as well. Since suppliers are not familiar with the system, they feel insecure and think that confidentiality issue is compromised." Supply Chain Procurement Officer from UN based organization in Ethiopia office, e-tendering practitioner.*

Similarly, NVivo generated this node model as shown under Appendix 3 by identifying various nodes (relating to barriers affecting e-tendering implementation) in the interview responses. The figure shows pictorial representations of the barriers affecting e-tendering implementation. NVivo generated this model automatically by linking the various barriers mentioned and discussed during the interview. It shows the identified patterns of themes from the interview transcript. (See Appendix 3).

Research validity & reliability check

- **Scale reliability: Cronbach's alpha**

SPSS 25.0 was used to compute the *Cronbach's alpha or α* value for all of the factors and items listed in the questionnaire i.e., the CSFs & barriers of adapting e-tendering. Accordingly, Cronbach's alpha values for the CSFs (inclusive of five sub-factors), and barriers (inclusive of four sub-factors) of e-tendering implementation are calculated at .899, .844, .804, (.841, .882, .732, .820, .674) and (.557, .799, .697, .794) respectively and all the figures are much closer to and/or higher than the minimum acceptable threshold i.e., 0.6[11].

- **Scale validity: Factor analysis**

Factor analysis (FA) is a statistical method used to determine the relationship between components of a dataset (Kapoor, 2020). Even though the questionnaire used in the study was the same for all respondents, it was not the same instrument for the researcher, since a separate FA has to be established for each instrument. Thirty-seven (37) separate items were used in the questionnaire to measure two constructs or dimensions i.e., potential success factors (CSFs) and potential barriers of e-tendering implementation in the study area.

Accordingly, Exploratory Factor Analysis (EFA) has been applied to explore or determine the most effective factors/construct on e-tendering

[11] Although different scholars states 0.7 to be the minimum value for Cronbach's Alpha, a commonly applied rule of thumb i.e., an alpha of 0.6 – 0.7 is also acceptable (Hair JR et al., 2010; Shakya, 2015).

implementation and the group of measured variables based on the data, so that some meaningful pattern can be brought out of it. As the data from the questionnaire was to be used in a further analysis, it was decided to carry out an EFA using the Principal Component Analysis (PCA) factoring technique, using the most widely used Orthogonal rotation kind i.e., Varimax rotation. A Spearman's rho correlation of all the items was carried out in SPSS 25.0. From the number of rules that can be used to retain factors, Kaiser criterion or Eigen value > 1 rule & the scree plot were adopted for this study. Finally, an EFA was run on the two dimensions separately. Accordingly;

- **CSFs of e-tendering implementation:** the KMO measure (.685) and Bartlett's test for this construct showed conducting further FA was possible. Accordingly, the first round of FA produced 21 items under 6 different factors[12] that explained 70.7% of the total variance, in the data while each factor presented eigen values greater than 1 (3.49, 3.19, 2.76, 2.24, 1.97, and 1.22) after rotation and explained (16.62%, 15.17%, 13.13%, 10.64%, 9.37%, and 5.80%) of the scale's variance, respectively.

However, while looking at the rotated component matrix, factor 6 only consisted of two items (CSF 4.1& CSF 5.1) and item CSF 4.1 seems to cross-load on two components/factors i.e., factor loading value of .539 and .588 on factors 3 and 6 respectively. Among the options available to eliminate cross-loading, which is to look at their commonalities (values less than 0.4 are viewed insufficient), employ alternative rotation (to define a simpler structure), and/or to consider possible deletion of that particular item. Even if, the commonality of item CSF 4.1 is .688 i.e., above the minimum threshold and other alternative rotations have been applied to define a better structure, a cross-loading of the item persists. Therefore, the item was deleted and the second model was developed with a better factor structure and cross-loading was no longer an issue.

The second round of EFA produced 20 items under five (5) factors that have the most impact on e-tendering implementation and are extracted with initial eigenvalues of more than 1.0 and the % of variance explained by these components is higher than 50% i.e., 67.6%. These five factors as per the analysis are; Reliability of information communication & technology (Factor 1); Top management support & employee commitment (Factor 2); Reliability of users' acceptance (Factor 3); Reliability of legal factor (Factor 4); and Reliability of monitoring & evaluation system (Factor 5). The findings of the FA resulted a similar result with the different CSFs adopted initially when the research started (see Table 2 above). Except CSF 4.1 (trust of buyers & suppliers on the system) was deleted during the second model while conducting the FA.

- **Barriers of e-tendering implementation:** the KMO measure (0.54) and Bartlett's test for this construct showed conducting further FA was possible. The first round of FA produced 16 factors. The

[12] While conducting FA, SPSS does not generate names for each category instead the researcher is responsible to name the factors based on the construct or characteristic that the factors represent. Naming the factors is only important for the purpose of communication. As per the FA, the six factors are; Factor 1: CSF 2.2, CSF 2.3, CSF 2.5, CSF 2.1, CSF 2.4; Factor 2: CSF 1.2, CSF 1.3, CSF 1.4, CSF 1.5, CSF 1.1; Factor 3: CSF 4.4, CSF 4.3, CSF 4.2; Factor 4: CSF 3.3, CSF 3.1, CSF 3.2, CSF 4.1; Factor 5: CSF 5.2, CSF 5.3, CSF 5.4 and Factor 6: CSF 5.1, CSF 4.1. Codes used for observed variables are annexed at the end.

analysis of the principal component using scree plot test and Kaiser criterion for the CSFs construct resulted in 5 factors that explained 71.68% of the total variance, in the data while each factor presented eigenvalues greater than 1 (2.71, 2.67, 2.35, 2.14, and 1.59) after rotation and explained (16.96%, 16.69%, %, 14.69%, 13.37%, and 9.95%) of the scale's variance, respectively.

However, while looking at the rotated component matrix, factor 4 only consisted of two items (Bar 3.3 & Bar 1.2) and item Bar 1.2 seems to cross-load on two components/factors. Since latent variable having two items are likely to have low reliability, deletion of factor four or items under this factor was recommended. Due to this, instead of deleting both items, only item 'Bar 3.3' was deleted. This was because the original reliability of the respective construct showed a better result when item Bar 3.3 was deleted than item Bar 1.2. On top of that, the analysis result from the questionnaire showed that item Bar 1.2 was ranked on the top ten challenging factors, whereas item Bar 3.3 was not. This can be taken as empirical evidence to keep the item i.e., Bar 1.2. As EFA was re-run after deletion of an item and the second model came up with four factors[13] i.e., Environmental barriers (Factor 1); Managerial barriers (Factor 2); organizational barriers (Factor 3); and technological barriers (Factor 4).

[13] As per the FA, the five factors are; Factor 1: Bar 4.1, Bar 4.2, Bar 4.3, Bar 4.4; Factor 2: Bar 2.1, Bar 2.3, Bar 2.4; Factor 3: Bar 3.1, Bar 3.2, Bar 3.4; and Factor 4: Bar 1.1, Bar 1.2, Bar 2.2. Codes used for observed variables are annexed at the end.

6. Conclusion & recommendation

Since the introduction of the system by the Government of Ethiopia (GoE) is still at its elementary level, factors affecting its adoption/implementation were considered by taking the perception of experts in the study area into account.

The FA conducted in this study resulted in different factor structures under each construct, each of which were discussed in detail in the previous sections. In the FA the statistical result from the study assigned variables to factors. However, it is appreciated if further FA i.e., a Confirmatory Factor Analysis (CFA) is conducted to test the extent to which the study's findings of factors loadings on prespecified constructs represents the actual data.

The study generally showed that the implementation of e-tendering is at elementary level and from the interview conducted, as well as from the findings of (Federal Public Procurement and Property Administration Agency, 2018) that less concern was given among public bodies and procuring entities regarding EP implementation in Ethiopia during pilot[14] stage. Thus, it is highly recommended that trainings or capacity building programs need to be setup. Frequent and/or regular seminars about the system should be held at national and/or organization level to increase users' awareness and future adoption. EP implementing agencies should make sure processes are efficient before applying automated solutions.

[14] List of 8 pilot procuring entities selected for EP implementation in Ethiopia: Ethiopian Pharmaceuticals Fund and Supply Agency (EPSA), Public Procurement and Property Disposal Service (PPDS), Addis Ababa University (AAU), Ethiopian Roads Authority (ERA), Ministry of Innovative and Technology (MiNT) or former MCIT, Ministry of Revenue (MoR), Ministry of Finance (MoF) and Federal Public Procurement and Property Administration Agency (FPPPAA).

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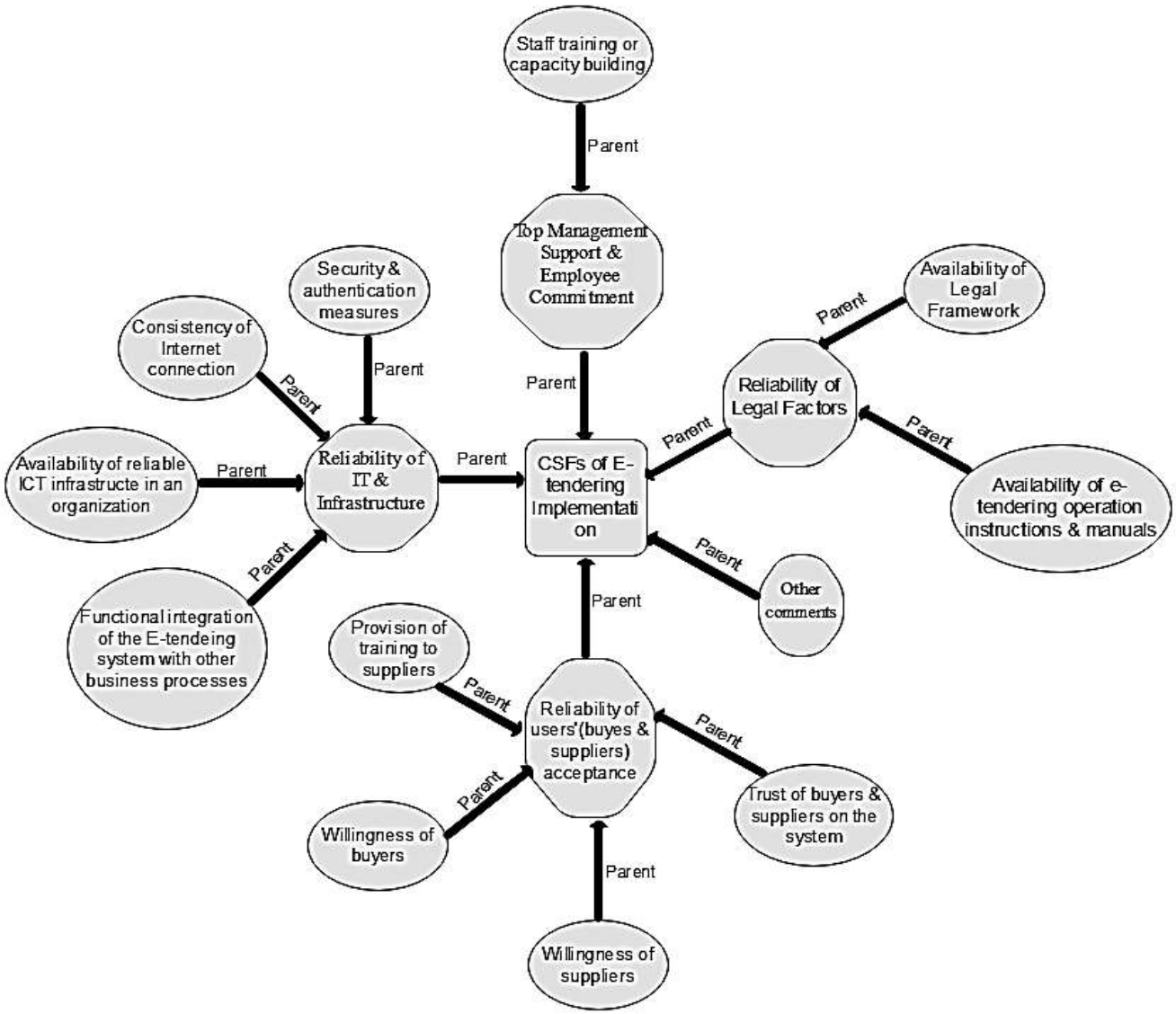
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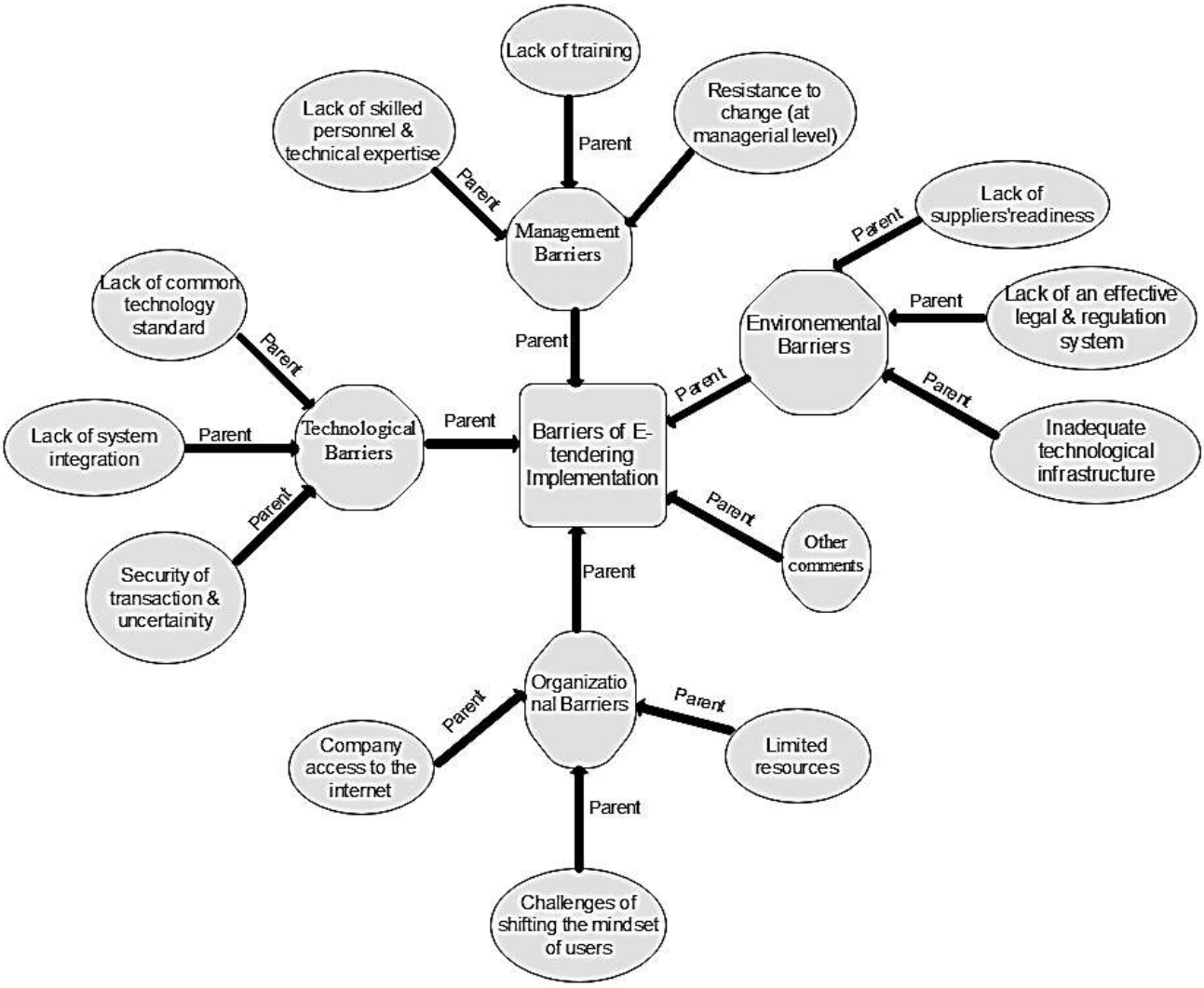
APPENDIX 1: Codes used for observed variables

Codes		Description of observed variable
CSF1: Top Management support & employee commitment	CSF1.1	Staff training/capacity building
	CSF1.2	Provision of adequate resources
	CSF1.3	Employee's commitment
	CSF1.4	The skill of procurement employees with IT perspective
	CSF1.5	E-tendering implementation strategy
CSF2: Reliability of Information Technology & infrastructure	CSF2.1	Consistency of internet connection
	CSF2.2	Availability of reliable ICT infrastructure within an organization
	CSF2.3	Compatibility of existing hardware & software with the e-tendering implementation system
	CSF2.4	Functional integration of the e-tendering system with other business processes
	CSF2.5	Security & authentication measures
CSF3: Reliability of legal factor	CSF3.1	Availability of e-tendering operation instructions & manual
	CSF3.2	Availability of legal & administrative procedures
	CSF3.3	Availability of legal framework
CSF4: Reliability of users' (buyers & suppliers) acceptance	CSF4.1	Trust of buyers & suppliers on the system
	CSF4.2	The willingness of employers to use e-tendering
	CSF4.3	The willingness of suppliers to adopt e-tendering
	CSF4.4	Provision of training programs to suppliers
CSF5: Reliability of monitoring & evaluation system	CSF5.1	Existence of a project management team to monitor & evaluate the progress of its implementation
	CSF5.2	Continuous evaluation & feedback
	CSF5.3	Compliance with rules & regulations is ensured
	CSF5.4	Checking procurement guidelines are practices & monitored
Bar1: Technological	Bar1.1	Lack of system integration i.e. interoperability & compatibility with other systems

Codes		Description of observed variable
barriers	Bar1.2	Insufficient assessment of systems before installation
	Bar1.3	Security of transaction & uncertainty (confidentiality violation)
	Bar1.4	Lack of common technology standard
Bar2: Management barriers	Bar2.1	Lack of skilled personnel & technical expertise
	Bar2.2	Lack of training/capacity building programs
	Bar2.3	Resistance to change (at managerial level)
	Bar2.4	Lack of leadership/upper management support
Bar3: Organizational barriers	Bar3.1	Staff turnover
	Bar3.2	Limited resources i.e., financial resource & time
	Bar3.3	Company access to the internet
	Bar3.4	Challenge in shifting the mindset of users
Bar4: Environmental barriers	Bar4.1	Inadequate technological infrastructure
	Bar4.2	Lack of national IT policy relating to EP issues
	Bar4.3	Lack of an effective legal & regulation system
	Bar4.4	Lack of suppliers' readiness



APPENDIX 2: CSFs Node Model: Relationship among Nodes



APPENDIX 3: Barriers Node Model: Relationship among Nodes

Contractors' Competitiveness in the Works Procurement of Federal Road Projects for International Competitive Bid

[1]Hanna Moges Dereje, [2]Wubishet Jekale Mengesha

Abstract

In construction, a procurement system is an essential tool used to establish criteria and award projects for contractors that fulfill them. The competitiveness of contractors is among the many criteria used in the selection process. Despite the different capacity-building programs for domestic contractors' competitiveness to participate in and undertake, international competitive bids of road projects in Ethiopia, most of them are awarded to foreign bidders. Hence, this study set out to assess the challenges domestic road contractors face when bidding for international competitive bids of federal road projects to find improvement mechanisms. A broad review and desk study of the past five years' bids eligibility criteria under Ethiopian Road Authority and Works procurement information of international competitive bids was carried out to explore local contractors' stand in bidding and their competitiveness. Also, data were collected through questionnaires disseminated to grade one road contractors also procurement directorate staff; and interviews conducted with senior officials from Ethiopian Road Authority to give the study more depth. Procurement data collected from 2014/2015 to 2019/2020 years showed that less than 37% of international competitive bids invited were awarded to local bidders. The major challenges identified for this include, irresponsive bids, inadequate contract administration system, inadequate experience, lack of well-equipped staff, inability to meet the required annual turnover, low-performance evaluation as well as lack of access to foreign currency. Improvement mechanisms such as building core competency and improving competitive advantage were some of the results of the research.

Keywords: Contractor, Competitiveness, Procurement, International Competitive Bid

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1. Introduction

1.1 Background

Ethiopia's economy is experiencing strong, broad-based development, mainly the construction and services businesses accounted for the major part of the growth in line with few businesses (World Bank, 2010). Almost every business hinges on the availability of business opportunities such as markets and customers. Contractors survive in business simply because they are doing business, and by being employed. One of the approaches used by contractors to remain in business is through direct engagement by the employer/buyer or through tendering (Alemu, 2015).

As per the Organization for Social and Economic Development report (MoFED,2013) on average in developing countries, public procurement accounts for up to 5% of GDP and 20% of public expenditures. This huge budget allotment makes procurement the heart of government operations (Anshebo, 2017).

Ethiopian Road Authority is one of the biggest government offices in the country and has its procurement and tendering procedures with eligibility and evaluation criteria (ERA, 2002). This office has been practicing international competitive bidding for a while now. The tenders by the entity were attractive enough to foreign competitors too. This made the degree of competition high.

Competitiveness is the ability of the company to compete with its competitors. Porter (1980) stated that competitive advantage is key to achieving superior performance. The construction industry is dynamic and has special characteristics for each area and has different impacts on the construction project competition. Competitiveness, in the past few decades, has received attention from practitioners and researchers in many industries across the globe. How to strengthen and support bidders' capabilities and core competencies to sustain the business and build their competitive and comparative advantage was the main goal basically like this research. A contractor's competitiveness for a project should be assessed not only by considering its commitments specified in the tender but also by its previous experience and current capacity (Flanagan, 2007). Besides, Shen (2004) proposes that the assessment of competitiveness for a project should take into account the characteristics of the local market. While acknowledging that a contractor's competitiveness varies according to project attributes. Drew and Skitmore (1997) focused on the firm's resources for competitiveness. Competitive bidding is compulsory in the public sector which provides the least qualified and competitive contractor. But, a contractor to

be competent enough in construction works bid faces numerous challenges. Some work, factors affecting the competitiveness of contractors briefly in Table 1.

Table 1. Review summary of factors affecting the competitiveness of contractors

Author	Country	Field of area	Factors
Tan et al. (2008)	Hong Kong	Construction project management	Employer selection criteria, Tenderer's cost planning, Project conditions, Contractual mechanism, Tenderer's external relationship, Tenderer's internal strength, Competitors' situation
Drew and Skitmore (1993)	Australia	Construction Engineering Management and Economics	Market conditions, number, and identity of competitors. Individual contractor behavior; contractor size, work, tenders in hand, availability of staff. and behavior towards the characteristics of the contract; type and size of construction work, client, location
Drew and Skitmore (1997)	Australia	Construction Engineering Management and Economics	Market conditions, number and identity of competitors, individual contractor behavior (e.g., contractor size, work and tenders in hand, availability of staff); and behavior towards the characteristics of the contract (e.g., type and size of construction work, client, location).
Hatush and Skitmore (1997)	United Kingdom	Construction project management	Financial soundness, technical ability, management capability, health and safety, and reputation.
Lu (2008)	Hong kong		Project management skills, organization structure, resources, competitive strategy, relationships, bidding, marketing, and technology

happen to be the company's internal issues and some external ones. Administration matters, lack of experience, staff reluctance, late bid submission, unethical behavior of bidder, etc. are among the many internal challenges (Drew, 1997; El-Karriri, 2008; Hong and Shum, 1999; Alexandersson and Hultén, 2006; Ngai and Wat, 2002). Social and economic conditions, bid security process, relationships with stakeholders, procurement regulations and policies, bid special requirements /uniqueness/, project size, etc. are some of the external problems for contractors' competitiveness (World Bank, 2004). Other than mentioned studies above, different researchers stated in their

According to the Ethiopian Road Authority's bid evaluation report (2002), most of the local bidders' competitiveness was weak compared to the foreign contractors.

The tendency of local Contractors to fail to qualify for further evaluation implies that challenges were facing them and still are. This matter highly affects the domestic contractors, not to mention the country's economy and construction business transaction advantages.

1.2 Motivation

Efforts and initiatives have been made to develop and empower local Contractors through Training. Also, experience sharing under Ethiopian Road Authority in

collaboration with foreign companies and expertise has been considered (Ethiopian Herald, 2019). Despite these efforts, most public ventures available for competition by local and international bidders normally end up with contracts being awarded to foreign contractors; this is saddening. This can be confirmed by not only the contract registered under the Ethiopian Road Authority (ERA) but by simply being observant of the road projects in the country and asking who the contractor is for the project. Maintenance of the existing gravel or paved roads of small road projects, there might be good stories executing them by domestic Contractors. However, it was not known why they were not effective players in large road projects such as building, upgrading and, rehabilitation works as compared to foreign ones. Thus, the researchers are motivated to study and analyze various challenges facing domestic contractors in the bidding process to draw up lessons for future efforts to develop, empower, and increase their market share in the procurement of federal ICB road projects.

1.3 Objectives

The study intends to achieve the following objectives:

- To find out the challenges affecting domestic contractors' competitiveness in the procurement of international competitive bidding of road construction projects.
- Study areas for improvement, to enable domestic Contractors to enhance their competitiveness and competitiveness strategy in international competitive bidding for federal road construction projects.

2. Methodology

2.1 Research Area

The study focused on domestic road contractors. Most of these contractors are based in the major business city, Addis Ababa. Hence, the study area was in the capital city of Ethiopia, Addis Ababa.

2.2 Research Population

The targeted population in this research was: Domestic road contractors registered in higher grades. Considering those are the contractors with exposure to international competitive bidding. Twenty-two contractors, sixteen Ethiopian road authority procurement staff, and five higher officials from ERA were addressed.

2.3 Population Sampling and Sampling Techniques

The research sampling has been thru non-probability sampling. Which were Snowball sampling and Purposive sampling.

2.4 Data Collection Instrument and Analysis

Besides the obvious secondary data, data from questionnaires, and interviews have been used. Additionally, bid evaluation reports by ERA for the past five years starting from the fiscal year of 2014/2015 to the fiscal year 2019/2020 were also data sources.

Microsoft Excel and the Statistical Package for Social Science (SPSS) were used in aiding the analysis and presentation of the findings of the research.

2.5 Research Instrument Quality Test

Validity

Face Validity Test: Review by experts

Content Validity Test: Raters (i.e. Contractors' Contract administration staff and ERA's engineering procurement directorate experts, and researchers) reviewed relevance in form of readability, clarity, and comprehensiveness and came to some level of agreement as to which items should be included in the final questionnaire and interview. The result of I-CVI and SCVI/UA was 0.96 and 0.83 respectively.

Hence, the result showed the item of the instruments were relevant enough.

Reliability

Cronbach's Alpha: The researchers conducted Alpha- Cronbach's Method reliability tests on the quantitative data sample. The result was Company's /Firm's/ characteristics α=0.809 for 24 items, Project/contract characteristics factors α= 0.789 for 10 items, Bidding situation α=0.888 for 13 items, Contract documentation and administration factors α=0.684 for 4 items, Tenderers' internal relationships α=0.731 for 4 items, The social and economic conditions α=0.679 for 7 items, and ERA's major factors α=0.749 for 7 items. Hence, the reliability statistics obtained from Cronbach's Alpha value is greater than 0.6, and based on decision-making in the reliability test can be concluded that this research instrument was reliable.

3. Result and Discussion

In particular, as the research aimed at addressing two objectives, the result with its discussion will follow in the order of the objectives.

3.1 The Challenges Domestic Contractors' Competitiveness faced in the procurement of ICB Road projects

I. Factors affecting local Contractor's competitiveness

Based on the different reviews such as (Drew and Skitmore, 1993; Tan et al., 2008; Hatush and Skitmore,1997; Lu, 2008), to mention a few, factors affecting domestic Contractors' competitiveness have been categorized into six for the study, i.e. project characteristics factors (10 factors), company's characteristics factors (24 factors), social and economic condition factors (6 factors), bidding situation factors (13 factors), contract documentation/ administration factors (4 factors), and tenderers' internal relationships (4 factors). And, they have been rated by the contractors.

The following table will present highly rated factors (critical factors) using the relative importance index from the six categories.

Table 2. Critical factors that affect Domestic Contractor's Competitiveness in ICB Road projects

Critical Sub Factors(CSFs)	(Importance Index) II	Rank
Financial resources and Financial stability for the bid (CSF 1)	97.27%	1
Experience in Certain kinds of bidding (CSF 2)	96.36%	2
Failure to meet the Turnover requirement of the ICB Tender (CSF 3)	93.64%	3
Past experience in similar ICB Road projects /company strength in the industry (CSF 4)	92.73%	4
Availability of qualified and Experienced Staff (CSF 5)	91.82%	5
Social, Economic and The political condition of the country (CSF 6)	91.82%	6
Completeness of Bid document (CSF 7)	90.00%	7
Bid Contract Conditions /special requirements/ (CSF 8)	90.00%	8
Managerial ability (CSF 9)	90.00%	9
Project cash flow (CSF 10)	89.09%	10
Project size (CSF 11)	88.18%	11
Contract Coordination difficulties (CSF 12	87.27%	12
Pre-qualification requirement (CSF13)	87.27%	13
Expected number of competitors (degree of competition) (CSF 14)	87.27%	14
Site Conditions (CSF 15)	87.27%	15
The Contract Administration System (CSF 16)	85.45%	16
The commitment of the Firm to ongoing projects (CSF 17)	85.45%	17
Contractors' Relationship with stakeholders (CSF 18)	84.55%	18
Government Procurement regulations (CSF 19)	84.55%	19

Financial resources and financial stability being the first to be ranked make it similar to Hatush and Skitmore's (1997) work with a name of financial soundness.

Experience in Certain kinds of bidding was ranked in the second position with an importance index of (96.36 %). This factor was found by Tan et al. (2008) within the key critical success factors that have a relative importance index of over 75%. This shows that having experience with staff who are qualified with different bidding types is

crucial to be successful for local contractors in ICB. Even though the Ethiopian Road Authority has preference margins to support the local contractor when it comes to the requirement of annual turnover, which is 70% of the engineer's estimate divided by the contract period in years (The peak value in the last five years) for local contractors, and 200% for foreigners (average value of the last five years), but based on the domestic contractors' response it was one of the crucial factors with 93.64% which tells it's not enough for the domestic ones. Other critical factors that follow with the rating fail in the category of company's (firm's) characteristics and bid situation factors. Also, in Ling and Liu (2005) and Tan et al. (2008), these factors were mentioned as important and critical factors affecting the bidder's competitiveness success, and strategies.

II. Rating of the Competitiveness of the local Contractors in ICB

ERA's respondents (i.e. 46.15%) considered the local contractors' bid unsatisfactory. The reason for unsatisfactory bid submission was answered as low-performance evaluation report, low annual turnover, low construction experience, lack of techniques to prepare an appropriate bid document, lack of knowledge on pricing, inability to submit duly completed bid documents, incomplete bid document, inability to provide supporting documents, trying to bypass the system through many mechanisms, bribery, mixing up technical and financial bid documents, lack of professionalism, lack of understanding of the scope required for the bid, missing bid submission date, fail to meet required previous project performance. In addition, the Ethiopian Roads Authority report for 2014/15 to 2019/20 is presented below.

Table 3. Works Procurement information from 2014/2015 to 2019/2020 years

Year	Total Number of ICB Contract signed	The total amount committed in birr	Contracts Won by Firms	
			Local	Foreign
2014/2015	6	12,035,555,893.51	Nil	(100%) 6
2016	25	34,213,692,412.53	(40%)10	(60%)15
2017	17	20,177,118,211.47	(41.2%)7	(58.8%)10
2018	26	42,847,464,198.16	(38.5%)10	(61.5%)16
2019/2020	23	45,668,338,480.31	(39.1%)9	(60.9%)14

It has appeared in the past years that domestic Contractors' success was 37.1%. Unfortunately, the rest and the majority of ICB projects were awarded to foreign contractors.

In the result of interviews of senior officers of ERA and questionnaires of the procurement directorate staff, lack of experience in ICB projects, inadequate access to credit, and unable to meet the annual turnover requirement of the Bid was the leading challenges. Additionally, inadequate approach and insufficient knowledge and experience required for the preparation of responsive bids, lack of owned equipment plants, and insufficient resources, inability to adequately provide bid securities, and inability to prepare the lowest bid prices mentioned.

III. ERA related shortcomings

Most respondents from the questionnaires, also interviews said the tender is well made and considers preferences for domestic contractors. But, contractors mentioned the performance rating criteria problem with lack of supervision, Financial and Equipment requirements of the ICB being too high, and the domestic contractor's capacity building program implemented by ERA has a problem of fit for purpose and it doesn't have regular follow-up with periodic evaluation were mentioned as a major drawback in ICB tender.

IV. Public Procurement Agency (PPA) Regulations and Government Policy

The interviewed participants were highly concerned with the policies and regulations the government bodies and offices have for competent local contractors, especially all the five interviewed higher officers continuously and similarly mentioned: foreign currency policy, a process of owning plants and equipment, donor /financer policy, outdated and unfit PPA regulations ICB projects, construction registration board standards for grading construction businesses, and fragmentation between regulatory bodies as a major gap. Hence, the regulation and proclamation of PPA and policies of other government bodies that are directly or indirectly related to the construction business; the conduciveness of the policies and regulations significantly affect the competitive strategy, also the way to success by the local contractors.

3.2 Improvement Mechanisms to enhance Domestic Contractors' Competitiveness in the procurement of ICB of Road Projects

- ***Domestic Contractors' Role and Responsibility: (Questionnaire result)***

Contractors need to hire experienced contract administrators; train technical staff according to ICB; bid filling processes, and new technologies to increase efficiency and effectiveness, Increase commitment to

ongoing projects, be legitimate and lawful, acquaintance with PPA, CRB, and ERA's procurement and evaluation system to influence policies and regulations so that it gets conducive enough, building good relationships and reputation with the stakeholders and solving disputes and litigation process timely, working on the value of money on the tender to enhance competitive strategies. Therefore, it shows the local contractors themselves know that strategies of competitiveness consider adequate market share, productive manner, and profitability as Mohammed et al. (2014) been mentioning with building core competence **(**Krasnokutskaya and Seim, 2007), and having a competitive and comparative advantage (Porter, 1994; Alberto Onetti, et al., 2012) were crucial. On the other hand, Tan et al. (2008) offered a competitive strategy of a lower bidding price than other competitors to increase the chance of winning the contract. But, on contrary, the finding of this research based on the interview showed low bid strategy might be a risk for profitability and losing market value. Alexandersson and Hultén (2006); Ngai and Wat (2002) agreed with that in their study.

- ***Ethiopian Road Authority, Public Procurement Agency, Government bodies Responsibility: (Interview and questionnaire result)***

ERA should provide regular training to contractors on bidding and bid submission strategies, also for its staff, and provide regulation for the provision of slots for local contractors, ERA needs to work on capacity-building programs intensively, formulate a suitable procurement management strategy, create a system that increases the participation of sub-contractors on ICB projects so that they can enhance their experience and capacity, regularly monitoring contractors' performance and supervision, regular assessment of Contractors' technical team and assist, revise the minimum Bid requirement to be fulfilled by the domestic contractors which set for the ICB projects, working on transparency and formal ways of communications, facilitate loan in the form of finance or goods for domestic Contractors, to create a stable system and enforce the requirement that major projects should be done by JV between local and foreign firms. Therefore, integration is another key factor, as Aidah Nassazi (2013) too mentioned in Uganda's business, it is a necessity to improve competitiveness internally and increase trust externally so that the company continues to gain the trust of the project owner to continue getting sustainable construction project work. The finding also relates highly to the improvement mechanism of Nurisra et al. (2018) and Kumaraswamy, (2000) which were

maintaining a good relationship with the government, owner, and consultant, considering joint ventures, etc.

4. Conclusion

The competitiveness of domestic road contractors in international competitive bids has been assessed through the experience of the local contractors and ERA staff. It is verified that local contractors' competitiveness depends on and is challenged by financial soundness, experience in international competitive bidding, and the company's strength in the industry. Hence, building their experience and financial capacity by considering a joint venture with locals and foreigners could be the major improvement mechanism of competitiveness. But, not just depending on building core competency but adding competitive and comparative advantage will enhance their competitiveness, especially for their technical evaluation. Even though the least bid is still a winner for the financial evaluation, considering the profit and market value, ethical bidder behavior to avoid low-balling and front-loading before the bid-offer is crucial for the domestic contractor to be competent in Ethiopia's ICB road projects. Identifying the necessity and enlightening Ethiopian road contractors, Ethiopian Road Authority, Construction procurement policymakers, and other stakeholders on competitiveness and its strategies so that to take what is rightfully theirs, and improve their stand in bidding has been addressed through this study. Further work on modeling the findings into a statistical framework will be in the future study.

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Understanding and managing landslide hazards in railway route selection

[1]Mariamawit WoldeGabriel , [2]Tewodros Gemechu

Abstract

Several factors are considered when deciding upon the route alignment of a new railway line. Geohazards, such as landslides, are often ignored in this phase and are given attention in later advanced stages of the project. This tacit practice may result in unsafe and/or uneconomic designs and/or make the design process a futile task if careful evaluation results in a redo of the whole design. This paper makes the case for due consideration of geotechnical hazards from the very early stages of route selection. This is accomplished through quantifying landslide hazards associated with the 'suggested' alternative routes, carrying out appropriate analysis of geotechnical data, performing probabilistic slope stability analyses using various methods and quantifying the reliability of a system of landslide hazards along a certain route to select the better alternative. System failure probabilities for the two alternative alignments of the planned railway are evaluated with Event Trees and Minimal Cut Sets with the assumption that the initiating event of the ground water level rise had occurred and that failure events in the designated landslide zones are mutually independent. It has been showcased that the better alternative can be chosen based on probability of failure calculated using several reliability methods. The efficiency of the methods in determining component and system reliability parameters has also been discussed.

Keywords: FORM, FOSM, minimal cut sets, Monte Carlo simulation, and reliability

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1.Introduction

Of the common geohazards, landslide has proved to be the most stubborn one in Ethiopia. Given the fact that landslides have been reported to be frequent and disastrous, it is paramount to consider these hazards during the design, construction and management of new railway/highway lines. This can be accomplished through quantifying landslide hazards associated with the 'suggested' alternative routes, carrying out appropriate analysis of geotechnical data, performing probabilistic slope stability analyses using various methods and quantifying the reliability of a system of landslide hazards along a certain route in order to select the better alternative.

Most of the parameters used in geotechnical analyses, in particular the mechanical soil properties, are uncertain. Working with uncertainty is therefore an essential aspect of geotechnical engineering – the larger the uncertainty and the closer to critical, the greater the need for evaluating its effect(s) on the results. The geotechnical engineer tries to deal with the uncertainties by choosing reasonably conservative parameters for the deterministic stability evaluation. This approach, however, fails to address the problem of properly and consistently dealing with uncertainties. [1]

Model uncertainties are usually characterized by separate parameter. Probability theory and reliability analyses provide a rational framework for dealing with uncertainties and decision making under uncertainty. Depending on the level of sophistication, the analyses provide one or more of the following outputs: probability of failure (or probability of unsatisfactory performance), reliability index, the most probable combination of parameters leading to failure, sensitivity of result to any change in parameters.

Well-established reliability methods, such as FOSM, FORM/SORM and Monte Carlo simulation, which have been utilized in this paper, are useful techniques for determining the reliability of geotechnical designs for estimating the probability of failure. The reliability methods also reveal which parameters contribute most to the uncertainty and probability of failure. [2]

2. Problem definition

Two alternatives are considered for the future position of the railway, denoted I and II in Figure 4. Due to the specific configuration of the terrain, in alternative I, the future railway is planned to be built next to the existing highway. In alternative II, the future railway is planned to be built on the opposite side of the lake with respect to the existing highway.

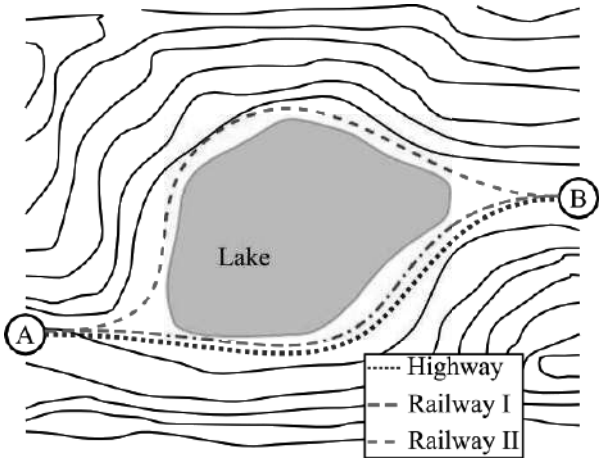


Figure 1 Alternative routes for the railway

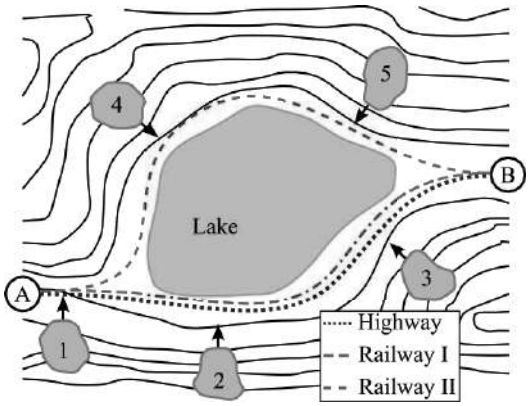


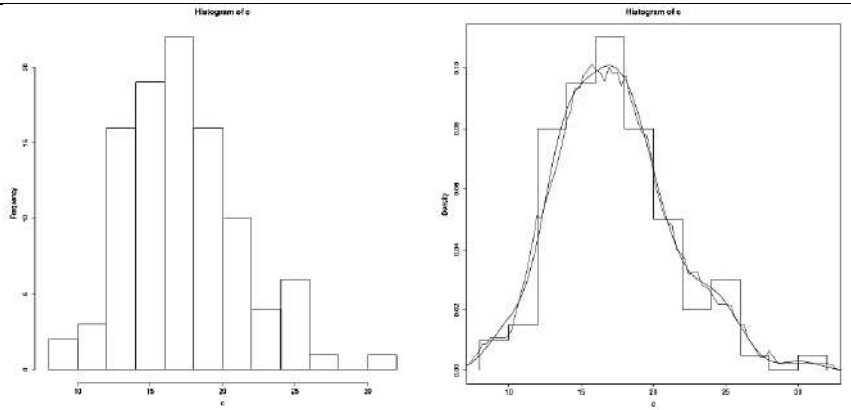
Figure 2 Potentially unstable regions

Potential slope failures in the region surrounding the valley represent a threat to the operable connection between the level in the slopes surrounding the valley. Increased ground water level can destabilize slopes and lead to slope failure. Based on the geological and geotechnical site investigations on the possible railway routes, five potentially unstable slopes were detected as presented in Figure 5. Failure of any of the detected slopes is expected to damage the nearby highway and/or railway. Factor of safety of the detected slopes can be evaluated by a relatively simple infinite slope model with steady state seepage. For simplicity, it is assumed that the ground water level coincides with the ground surface with seepage parallel to the slope surface.

3. Data characterization

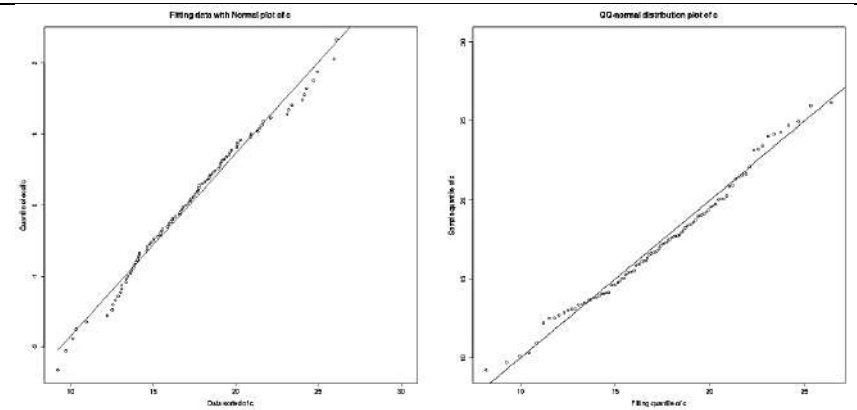
In this section, parameters of the slope stability equation are analyzed individually using MATLAB software. Histograms and kernel density estimations have been generated to visualize the data set and its central tendencies. (See figures 6, 10, 14 and 18 respectively for cohesion, angle of internal friction, saturated unit weight and depth to bed rock). The data set is then plotted on probability paper, quantile-quantile plots generated, and best fit distribution(s) identified from among normal, log-normal, Gumble, and uniform options. The choice among the aforementioned continuous probability distributions is then summarized in Table 1.

Cohesion C



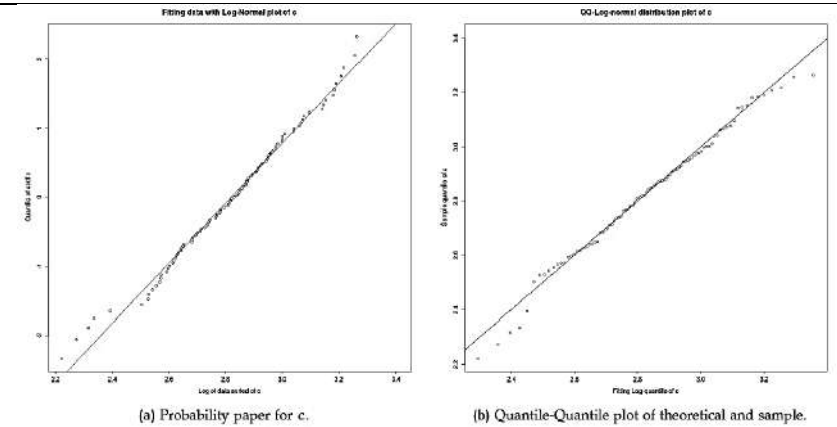
(a) Cohesion sample on a histogram. (b) Kernel density estimation.

*Figure 3 Visualization of **c** data*



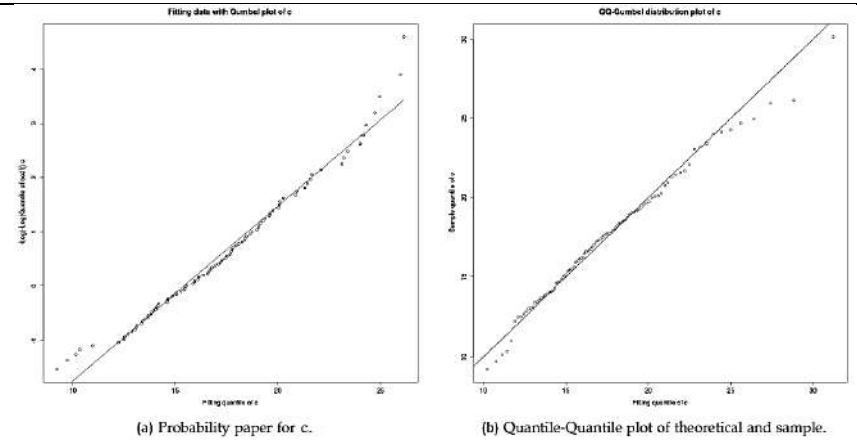
(a) Probability paper for c. (b) Quantile-Quantile plot of theoretical and sample.

Figure 4 Normal distribution for c



(a) Probability paper for c. (b) Quantile-Quantile plot of theoretical and sample.

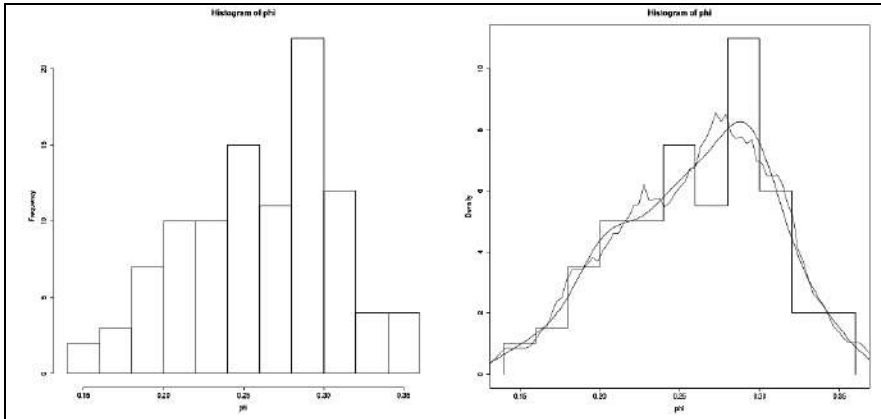
Figure 5 Log-Normal distribution for c



(a) Probability paper for c. (b) Quantile-Quantile plot of theoretical and sample.

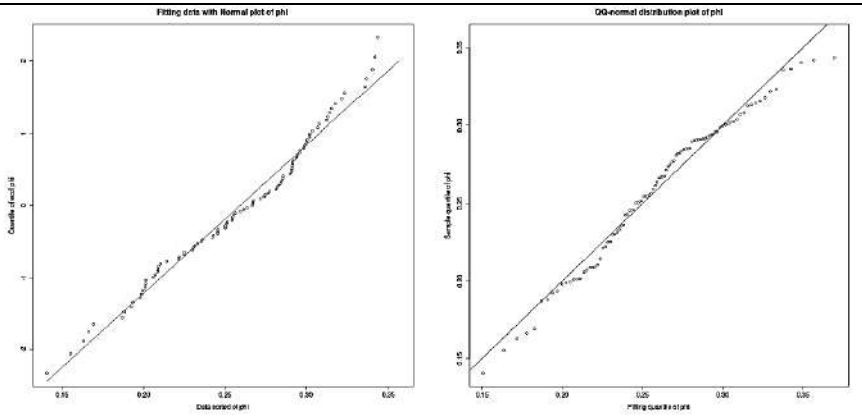
Figure 6 Gumbel distribution for c

Angle of Internal Friction φ



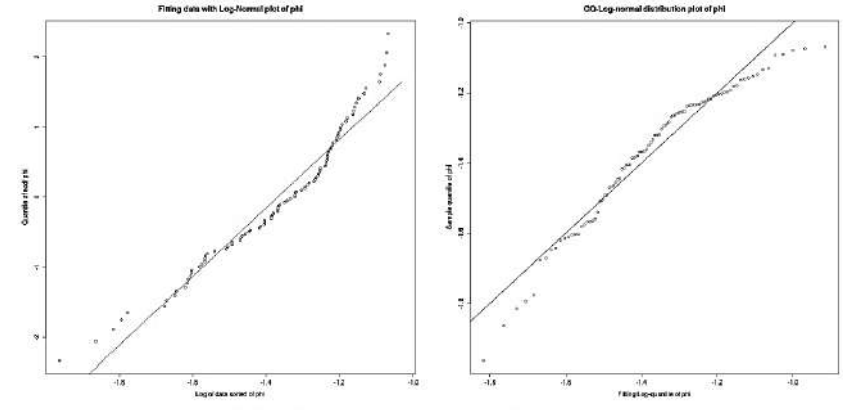
(a) Friction angle sample on a histogram. (b) Kernel density estimation.

*Figure 7 Visualization of **φ** data*



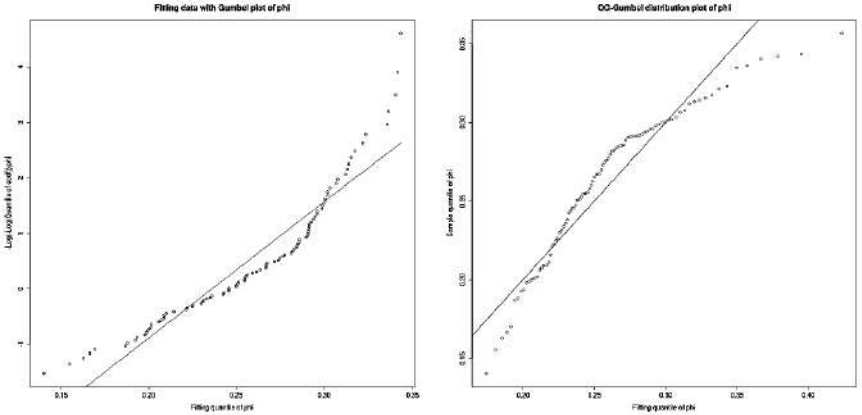
(a) Probability paper for ϕ. (b) Quantile-Quantile plot of theoretical and sample.

Figure 8 Normal distribution for φ



(a) Probability paper for ϕ. (b) Quantile-Quantile plot of theoretical and sample.

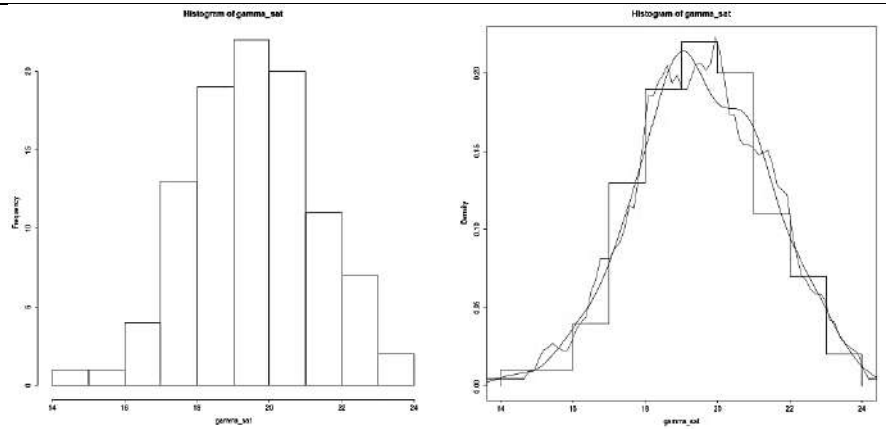
Figure 9 Log-Normal distribution for φ



(a) Probability paper for ϕ. (b) Quantile-Quantile plot of theoretical and sample.

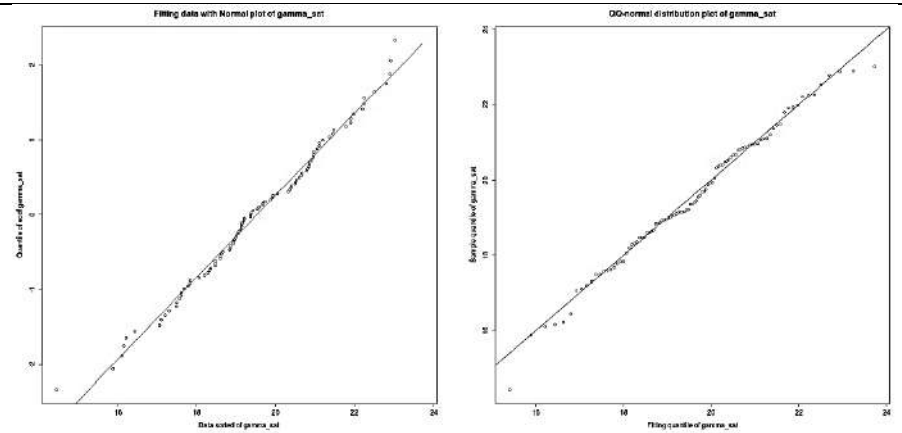
Figure 10 Gumbel distribution for φ

Saturated Unit Weight γ_{sat}



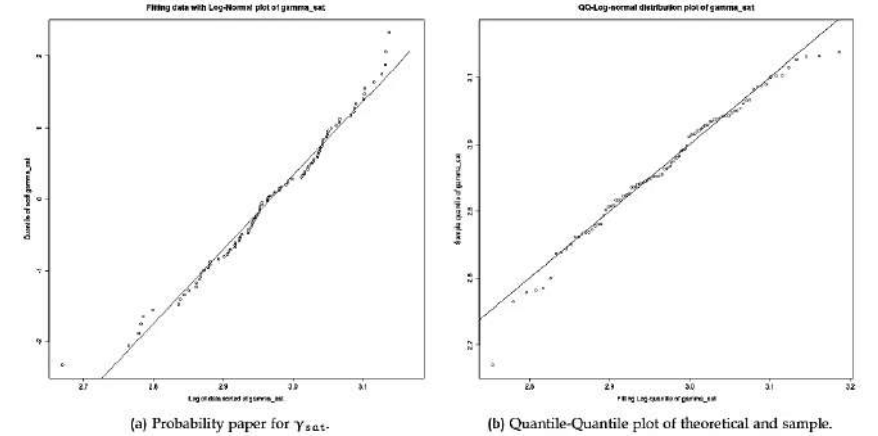
(a) Friction angle sample on a histogram. (b) Kernel density estimation.

Figure 11 Visualization of γ_{SAT} data



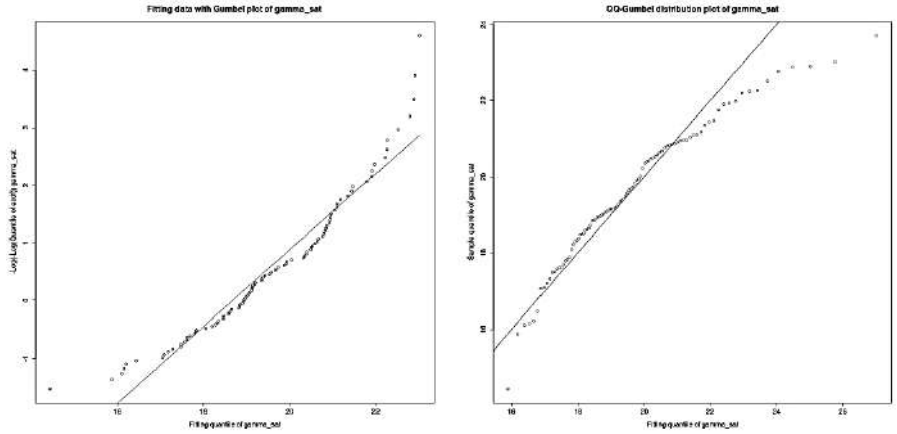
(a) Probability paper for γ_{sat}. (b) Quantile-Quantile plot of theoretical and sample.

Figure 12 Normal distribution for γ_{SAT}



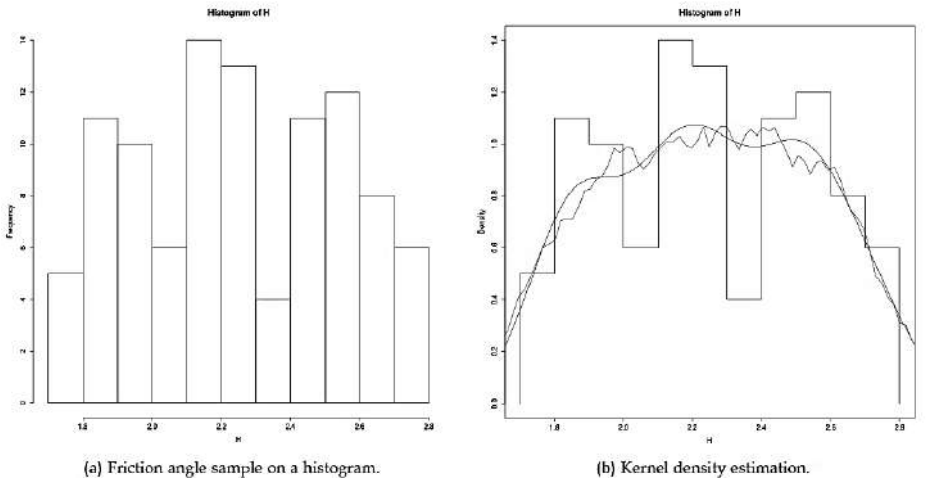
(a) Probability paper for γ_{sat}. (b) Quantile-Quantile plot of theoretical and sample.

Figure 13 Log-Normal distribution for γ_{SAT}



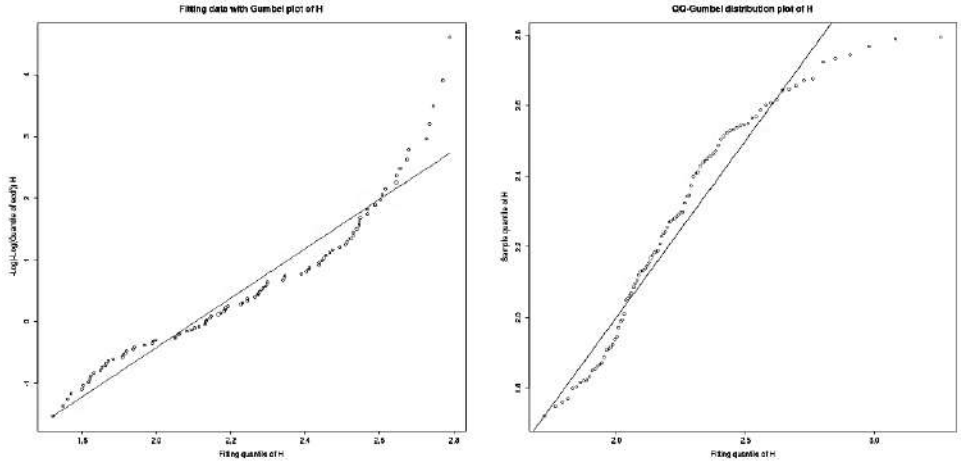
(a) Probability paper for γ_{sat}. (b) Quantile-Quantile plot of theoretical and sample.

Figure 14 Gumbel distribution for γ_{SAT}



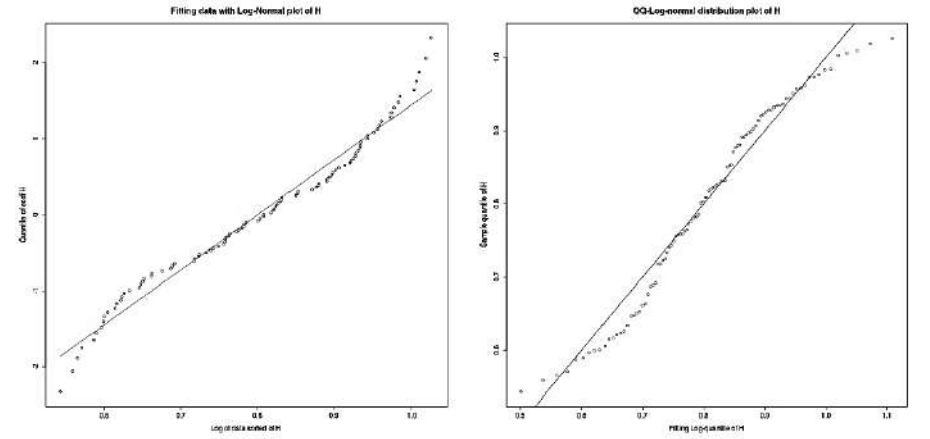
(a) Friction angle sample on a histogram. (b) Kernel density estimation.

*Figure 15 Visualization of **H** data*



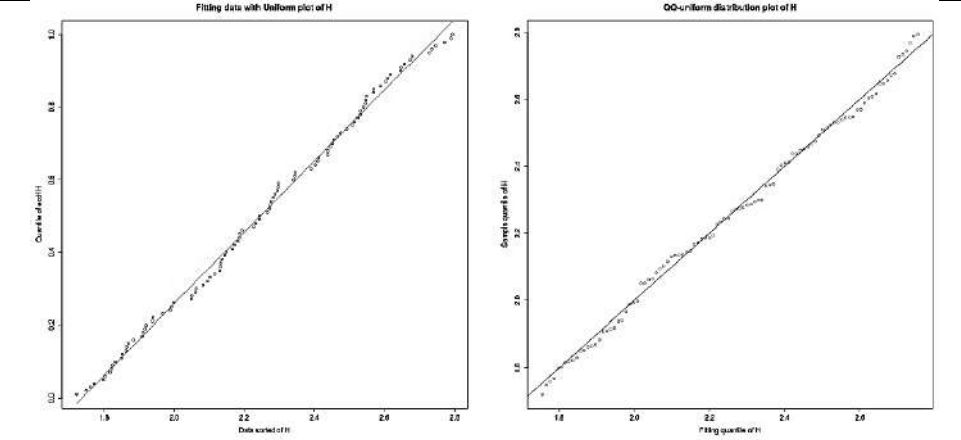
(a) Probability paper for H. (b) Quantile-Quantile plot of theoretical and sample.

Figure 16 Gumbel distribution for H



(a) Probability paper for H. (b) Quantile-Quantile plot of theoretical and sample.

Figure 17 Log-Normal distribution for H



(a) Probability paper for H. (b) Quantile-Quantile plot of theoretical and sample.

Figure 18 Uniform distribution for H

Table 1 Parameters for the random variables on zone 1

Random Variable	Distribution	Mean μ	Standard deviation σ
c	Log-normal	*17.3172016*	*3.99564399*
φ	Normal	*0.2601383*	*0.04705633*
γ_{sat}	Normal	*19.5675286*	*1.79113136*
H	Uniform	*2.2500858*	*0.2910438*

Table 2 Parameters for the random variables in all the five zones

Random Variable	Unit	Distribution	Parameters	Zone#1	Zone#2	Zone#3	Zone#4	Zone#5
ϵ	[/]	Normal	μ_ϵ	1	1	1	1	1
			σ_ϵ	0.1	0.1	0.1	0.1	0.1
c'	kPa	Log-normal	$\mu_{c'}$	17.3172016	13.8537613	14.2001053	21.1269860	16.4513416
			$\sigma_{c'}$	3.99564399	3.59607959	4.31529551	3.75590535	3.51616671
Υ_{sat}	$\frac{kN}{m^3}$	Normal	$\mu_{\Upsilon sat}$	19.5675286	18.0021263	18.9805027	18.3934768	20.3502297
			$\sigma_{\Upsilon sat}$	1.79113136	1.54037297	1.75530873	1.95233318	1.82695399
H	m	Uniform	μ_H	2.2500858	2.9251115	2.1150806	2.8351081	3.1276192
			σ_H	0.2910438	0.3550735	0.2997752	0.2677603	0.3026856
θ	rad	Normal	μ_θ	0.2094000	0.1675200	0.2261520	0.2177760	0.2261520
			σ_θ	0.0349000	0.0286180	0.0373430	0.0387390	0.0307120
Φ	rad	Normal	μ_Φ	0.2601383	0.2991591	0.2523342	0.3017605	0.3225715
			σ_Φ	0.0470563	0.0442330	0.0418801	0.0531737	0.0545853

First-Order Second-Moment (FOSM)

$$FS = \frac{\in}{\gamma_{sat} \tan\theta}\left(\frac{c'}{H\cos^2\theta} + (\gamma_{sat} - \gamma_w)\tan\phi'\right)$$

Eq. 1

$$\mu_g = E[Y] \approx g(\mu) = g(\mu_{X1}, \mu_{X2}, \ldots \mu_{XN})$$

$$\sigma_g^2 = Var[Y] \approx \sum_{i=1}^{N}\sum_{j=1}^{N} Cov(X_i, X_j)\left(\frac{dg}{dX_i} \cdot \frac{dg}{dX_j}\bigg|_{\mu}\right) \approx \sum_{i=1}^{N}\left(\sigma X_i \frac{dg}{dX_i}\bigg|_{\mu}\right)^2$$

$$\mu F_s = \frac{\mu_\epsilon}{\mu_{\gamma_{sat}} tan\,\mu_\theta}\left(\frac{\mu_{c'}}{\mu H\, cos^2\,\mu_\theta}\right) + \left(\mu_{\gamma_{sat}} - \gamma_w\right) tan\,\mu_{\Phi'}$$

$$\frac{\delta F_s}{\delta \epsilon} = \frac{-(\gamma_w H\cos^2\theta\tan\Phi' - c' - \gamma_{sat} - \gamma_w)\tan\Phi'}{\gamma_{sat} H cos^2\theta tan\theta}$$

$$\frac{\delta F_s}{\delta c'} = \frac{\epsilon}{\gamma_{sat} H cos^2\theta tan\theta}$$

$$\frac{\delta F_s}{\delta \gamma_{sat}} = \frac{\epsilon(\gamma_w H cos^2\theta tan\Phi' - c')}{\gamma_{sat}^2 H cos^2\theta tan\theta}$$

$$\frac{\delta F_s}{\delta H} = 2\cdot\frac{\epsilon c'}{\gamma_{sat} H} sec^2\,\theta - \frac{\epsilon\, csc^2\,\theta}{\gamma_{sat}} \cdot \left(\frac{c'}{H} sec^2\,\theta + (\gamma_{sat} - \gamma_w)\tan\Phi'\right)$$

$$\frac{\delta F_s}{\delta \varphi,} = \frac{\epsilon(\gamma_{sat} - \gamma_w)}{\gamma_{sat}\tan\theta\cos^2\theta}$$

The central tendencies of the factor of safety for all the five zones are summarized in Table 3.

Table 3 Parameters for the random variables on all the five zones

Parameters	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5
μ_{F_s}	2.546752	2.410962	2.148892	2.562381	1.921689
σ_{F_s}	0.721773 0	0.671204 2	0.688088 5	0.660417 3	0.444868 9

First-Order Reliability Method (FORM)

Reliability analysis tools namely SysRel and ComRel have been used to develop the sensitivity analysis outputs depicted below.

Performance function of the system is given by the following equation.

$$FLIM(1) = \frac{\varepsilon}{\gamma sat\ tan\theta}\left(\frac{c'}{H\ (cos\theta)\text{^}2} + (\gamma sat - \gamma w)tan\,\Phi'\right) - 1$$

Eq. 2

The calculated reliability index for each zone is summarized in Table 4 below.

Table 4 Reliability index for each zone using SysRel

Parameters	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5
β	3.468	3.286	2.475	3.814	2.775
P_f	0.2620E-03	0.5089E-03	0.6666E-02	0.6831E-04	0.2761E-02

Monte Carlo Simulation

Failure probabilities are calculated using Monte Carlo (MC) method by means of means and the standard deviations from the

original data and Ns = 10^6. The inverse transform method is applied to generate a set of distributed random numbers. The Excel maneuver inputs are summarized below in Table 5.

Table 5 Inverse distribution functions for each random variable

Random V.	Distribution	Φ()	Excel function
e	Normal	$\frac{e_i - \mu_c}{\sigma_c}$	*Norm.inv(Rand();μ_c;σ_y)*
c′	Log-normal	$\frac{\ln c'_i - \mu_y}{\sigma_{sat}}$	Lognorm.inv*(Rand();μ_y;σ_y)*
Υ_{sat}	Normal	$\frac{\Upsilon_{sat,i} - \mu_{\Upsilon_{sat}}}{\sigma_{\Upsilon_{sat}}}$	*Norm.inv(Rand();$\mu_{\Upsilon_{sat}}$;$\sigma_{\Upsilon_{sat}}$)*
H	Uniform	$\frac{H_i - \alpha}{\beta - \alpha}$	$(\beta - \alpha)$.Rand() + α
θ	Normal	$\frac{\theta_i - \mu_\theta}{\sigma_\theta}$	*Norm.inv(Rand();μ_e;σ_e)*
Φ	Normal	$\frac{\Phi_i - \mu_\Phi}{\sigma_\Phi}$	*Norm.inv(Rand();μ_Φ;σ_Φ)*

The outputs from MS Excel analysis are depicted for each zone in Figures 30 up to 34.

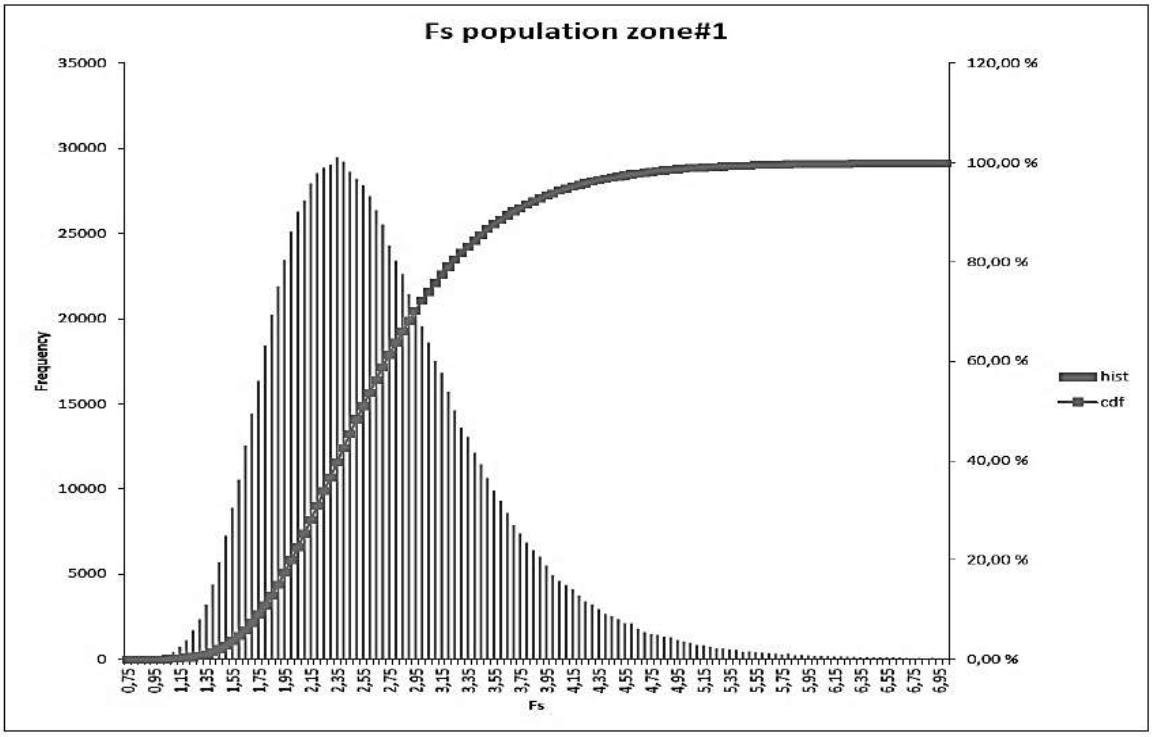


Figure 19 Diagram of sensitivity coefficients for zone#1

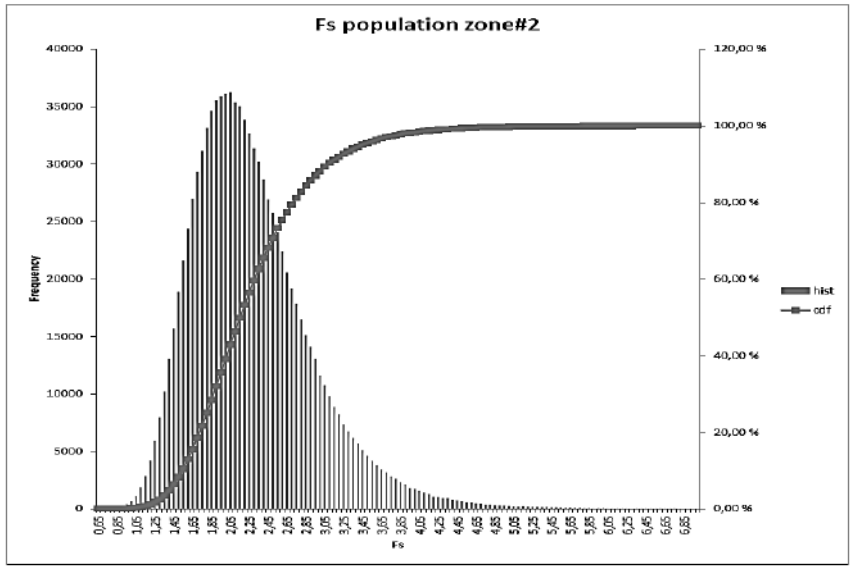


Figure 20 Diagram of sensitivity coefficients for zone#2

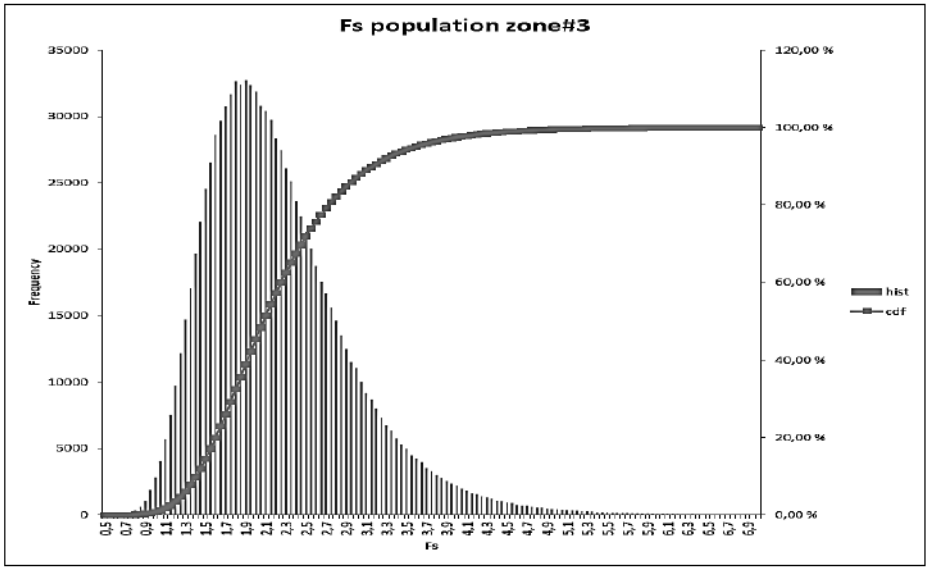


Figure 21 Diagram of sensitivity coefficients for zone#3

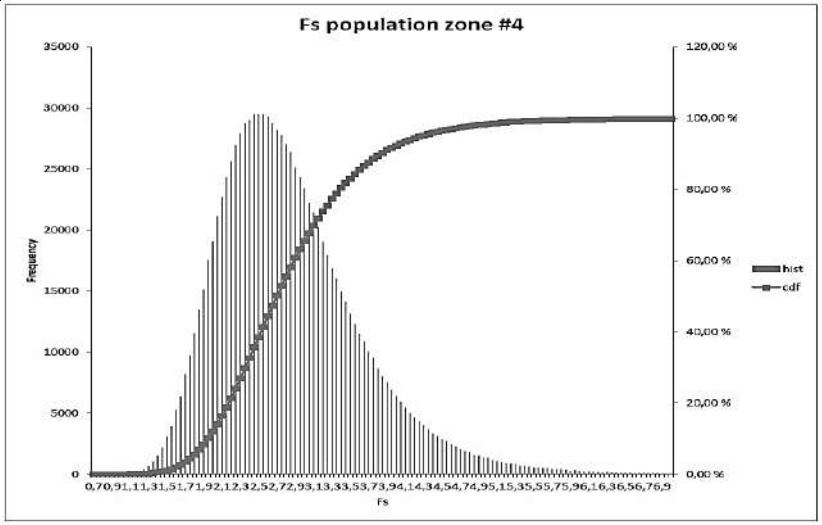


Figure 22 Diagram of sensitivity coefficients for zone#

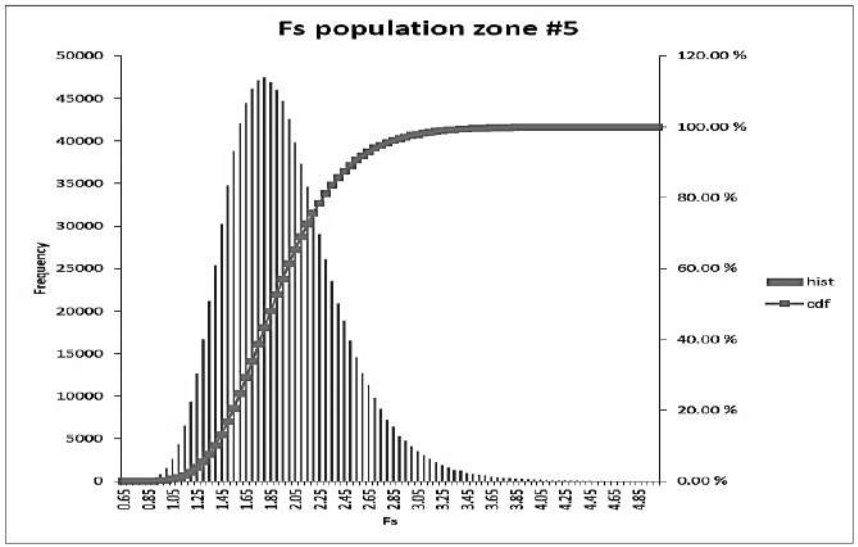


Figure 23 Diagram of sensitivity coefficients for zone#5

Event Tree Analysis

System failure probabilities have been evaluated for the two alternative positions of the planned railway with Event Trees. It is assumed that failure events in Zones 1 to 5 are mutually independent.

$S: Safe\ ;\ F: Fail\ ;$
$P_{is}: Probability\ of\ zone\ i\ to\ be\ safe\ ;$
$P_{if}: Probability\ of\ zone\ i\ to\ fail$

Alternative #1

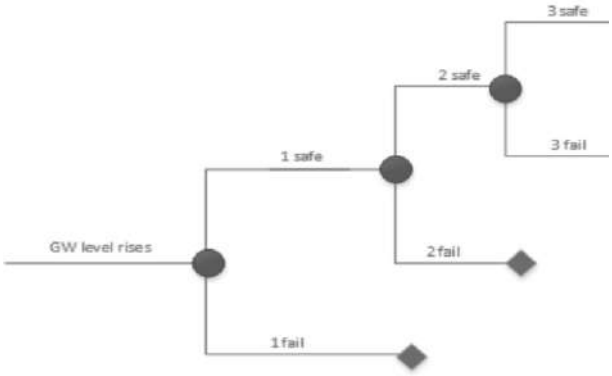


Figure 24 Event trees of the system with alternative #1

$$P_f^I = P_{1F} + P_{1S} \cdot P_{2F} + P_{1S} \cdot P_{2S} \cdot P_{3F} = P_{1F} + (1 - P_{1F}) \cdot P_{2F} + (1 - P_{1F})(1 - P_{2F}) \cdot P_{3F}$$

Alternative #2

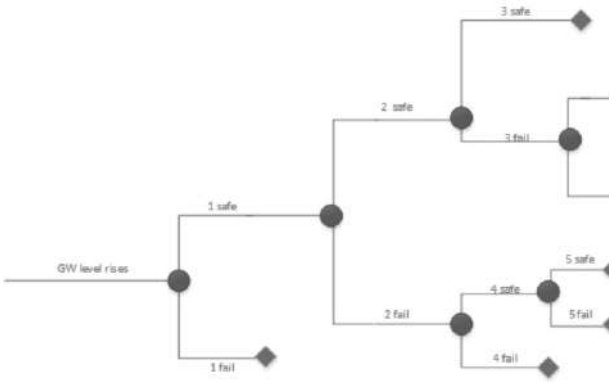


Figure 25 Event trees of the system with alternative #2

$$P_f^{II} = P_{1F} + P_{1S} \cdot P_{2S} \cdot P_{3F} \cdot P_{4S} \cdot P_{5F} + P_{1S} \cdot P_{2S} \cdot P_{3F} \cdot P_{4F} \cdot P_{1S} \cdot P_{2F} \cdot P_{4S} \cdot P_{5F} + P_{1S} \cdot P_{2F} \cdot P_{4F}$$

$$= P_{1F} + (1 - P_{1F})(1 - P_{2F})(1 - P_{4F}) \cdot P_{3F} \cdot P_{5F} + (1 - P_{1F})(1 - P_{2F}) \cdot P_{3F} \cdot P_{4F} + (1 - P_{1F})(1 - P_{4F}) \cdot P_{2F} \cdot P_{5F} + (1 - P_{1F}) \cdot P_{2F} \cdot P_{4F}$$

Minimal Cut Sets

Alternative #1

With the alternative #1 both the railway and the highway would be on the same side of the lake. The system failure probability is calculated as:

$$P_f^I = 1 - \prod_{i=1}^{N} (1 - P_{s_i}) \qquad \text{Eq. 3}$$

where

P_{s_i}: *the ith component failure probability and*
N: number of series components

The minimal cut of alternative #1 is series system where all components has to be active in order to give the possibility at the system to operates. Failure of each component results in system failure.

$$P_f^I = 1 - (1 - P_{s_1})(1 - P_{s_2})(1 - P_{s_3})$$

Alternative #2

With the alternative #2 the railway and the highway would be on the opposite sides of the lake. The system failure probability is calculated as:

$$P_f^{II} = 1 - \prod_{j=1}^{K} \left(1 - \prod_{i \in c_j} P_{s_i} \right) \qquad \text{Eq. 4}$$

where

P_{s_i}: $the\ ith\ component\ failure\ probability$
c_j: $set\ of\ minimal\ cut$
K: $number\ of\ series\ systems$

The system of alternative #2 is a complex system, it is a mixture of serial and parallel systems.

The system failure probability is equal to the probability that at least one minimal cut set fails.

$$P_f^I = 1 - \left(1 - P_{s_1}\right)\left(1 - P_{s_2} \cdot P_{s_4}\right)\left(1 - P_{s_2} \cdot P_{s_5}\right)\left(1 - P_{s_3} \cdot P_{s_4}\right)\left(1 - P_{s_3} \cdot P_{s_5}\right)$$

4. Results and discussion

The outputs of the component reliability analysis are summarized below.

.

Table 6 Mean and standard deviation safety factor for all the five zones with FOSM and MC

Parameters	Method	Zone#1	Zone#2	Zone#3	Zone#4	Zone#5
μ_{F_S}	FOSM	2.546752	2.410962	2.148892	2.562381	1.921689
	MC	2.658879	2.253238	2.206555	2.818103	1.928163
σ_{F_S}	FOSM	0.721773	0.6712042	0.688088	0.6604179	0.4448689
	MC	0.801679	0.6456817	0.741839	0.791604	0.460449

Table 7 Probability of failure for all the five zones with the two different methods

	Probability of Failure				
Method	Zone#1	Zone#2	Zone#3	Zone#4	Zone#5
FORM	0.2620E-03	0.5089E-03	0.6666E-02	0.6831E-04	0.26761E-02
MC	0.25E-03	1.366E-03	0.683E-02	0.29E-04	0.3029E-02

Comparing the probabilities of failure obtained with the two methods is evident as in some zones (1,3,5) the results are similar even if the two methods came from totally different approaches.

Table 8 Probability of failure of the system with two alternatives

Method for Probability	Method for system	Alternative #1	Alternative #2
FORM	Minimal cut	$7.4316 \cdot 10^{-3}$	$2.8229 \cdot 10^{-4}$
	Event trees	$7.4316 \cdot 10^{-3}$	$2.822838 \cdot 10^{-4}$
MC	Minimal cut	$8.4346 \cdot 10^{-3}$	$2.75057 \cdot 10^{-4}$
	Event trees	$8.434624 \cdot 10^{-3}$	$2.750279 \cdot 10^{-4}$

5. Conclusion

In terms of accuracy, MC method is better compared to FORM method, whereas in term of efficiency FORM is better. One can see that the standard deviation obtained from FOSM method is high compare to MC method. So, FOSM is less accurate than the MC method. From Table 8, it is apparent that **Alternative 1** carries a greater probability of failure across the board of all the methods utilized. As a conclusion, **Alternative 2** is a better option considering landslide hazard assessment outputs**.** As

showcased in this paper, railway engineers can work in tandem with geotechnical engineers from the early onset of a project so as to decide on the most technically sound alignment option. Instead of selecting an alignment solely based on cut and fill calculations, this option will provide additional dimension with great implication on safety and economy of a project.

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