**Supplementary Annexure I**

**Brief communication on the NW Himalayan towns; slipping towards potential disaster**

Yaspal Sundriyal1, Vipin Kumar2, Neha Chauhan1,Sameeksha Kaushik1, Rahul Ranjan3, Mohit K. Punia4

1Department of Geology, HNB Garhwal University, Srinagar, India

2Department of Geology, Doon University, Dehradun, India

3Oslo Metropolitan University, Oslo, Norway

4National Geotechnical Facility, Dehradun, India

\*Correspondence: [v.chauhan777@gmail.com](mailto:v.chauhan777@gmail.com)

**Slope stability analyses**

The slope stability analysis was performed under different load conditions, which required various input parameters of soil and rock. Soil parameters were determined in laboratory analysis (Supp. Table 1). Rock parameters are based on the supplementary data of Kumar et al. (2021b) owing to similarity of rockmass type. The soil samples were collected from both the locations (Fig.1, 2). The ALOS-PALSAR RTC DEM (©JAXA/METI, accessed through ASF DAAC, https://asf.alaska.edu, retrieved on 12/08/2022) was used to extract the topography. The topography was used to extract the 2D slope sections (CS1 to CS4) for the slope stability analysis. The soil samples were tested for grain size analysis (IS: 2720-Part 4-1985), UCS test (IS: 2720-Part 10-1991), and direct shear test (IS: 2720-Part 13- 1986). In the direct shear test, soil samples were sheared under constant normal stress of 50, 100 and 150 kN/m2. The UCS test of soil was performed under three different rates of movements i.e., 1.25 mm/min, 1.50 mm/min and 2.5 mm/min.

The Finite Element Method (FEM) - Shear Strength Reduction (SSR) based slope stability analysis was performed to infer the Total Displacement (TD) using the RS2 v.11.012 software. The boundary conditions with the restraining X and Y movements were applied to the base and back, whereas the front face of the slope sections was kept free for the movement. In-situ field stress was adjusted in view of dominant forces, i.e., compressional regime, by using the value of the coefficient of earth pressure (k) = (horizontal field stress) σh / (vertical field stress) σv = 1.5. The compressional regime was taken in view of the vicinity of the Main Central Thrust (NAT) fault (Supplementary Fig. 1). Notably, the FEM based slope stability analysis was performed in three stages. First stage involved static load i.e., field stress and body force, whereas second stage involved rainfall infiltration, domestic discharge (DD) infiltration, and building/house loads along with static load. Third stage involved dynamic load.

Rainfall infiltration (RF) is based on extreme rainfall in the region (Supp. Fig. 2) and the possibility of recurrence. The soil and rockmass were used in the FEM analysis through Mohr-Coulomb (M-C) failure criterion (Coulomb 1776; Mohr 1914) and Generalized Hoek-Brown (GHB) criterion (Hoek et al. 1995), respectively. Plane strain triangular elements having 6 nodes were used through the graded mesh in the models. Details of input parameters are present in following table. A configuration model with results in shown in Supp. Fig. 4.

**Supplementary Table 1**

|  |  |  |  |
| --- | --- | --- | --- |
| Rock mass |  | **Joshimath (JM)** | **Bhatwari (BT)** |
| Rock type | Gneiss | Gneiss |
| Soil type | Gravelly sand | Silty Sand |
| Unit Weight (MN/m3) | 0.025 | 0.027 |
| Peak rockmass  Modulus, Erm (MPa) | 5811.8 | 18546.3 |
| Residual rockmass modulus, Erm  (MPa) | 1395.1 | 9639 |
| Poisson’s Ratio | 0.26 | 0.26 |
| UCS, σci (MPa) | 110 | 115 |
| Peak GSI | 49 | 50 |
| Residual GSI | 15 | 40 |
| Material Constant, mi | 28 | 28 |
| Peak ‘mb’ | 1.699 | 4.695 |
| Residual ‘mb’ | 0.112 | 2.698 |
| Peak ‘s’ | 0.0006166 | 0.0038659 |
| Residual ‘s’ | 0.0000045 | 0.0012726 |
| Peak ‘a’ | 0.5061 | 0.5057 |
| Residual ‘a’ | 0.5611 | 0.5114 |
| Peak ‘D’ | 0.7 | 0 |
| Residual ‘D’ | 0.7 | 0 |
| Soil | Unit Weight (MN/m3) | 0.018 | 0.018 |
| Cohesion, C (MPa) | 0.01 | 0.01 |
| Angle of Friction, Ø (˚) | 30 | 38 |
| Young’s Modulus (MPa) | 4059 | 5320 |
| Poisson’s Ratio | 0.3 | 0.3 |
| Domestic discharge (MN/m3) | |  | 0.00981 |
| Rain infiltration (m/s) | |  | 1.18e-06 |
| Domestic Load (MN/m2) | |  | 0.007 |

**REFERENCES**

Coulomb, C. A. 1776. “An attempt to apply the rules of maxima and minima to several problems of stability related to architecture”. Mémoires de l’Académie Royale des Sciences 7: 343-382.

Hoek, E., Kaiser, P.K. and Bawden, W.F. 1995.Support of Underground Excavations in Hard Rock. Rotterdam: A. A. Alkema.

IS: 2720 (Part 10)–1991. “Method of test for soils: Determination of unconfined compressive strength”. In: Bureau of Indian Standards, Delhi, India.

IS: 2720 (Part 13)–1986. “Method of test for soils: Direct shear test”. In: Bureau of Indian Standards, New Delhi, India.

IS: 2720 (Part 4)–1985. “Methods of test for soils: Grain size analysis”. In: Bureau of Indian Standards, New Delhi, India.

Mohr, O. 1914. “Abhandlungen aus dem Gebiete der Technischen Mechanik” (2nd ed). Ernst, Berlin.