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Research Paper

Seismic Evaluation of Shallow Foundations for Safe Structures: A Case Study in Peshawar, Pakistan

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ABSTRACT*: The 2005 Catastrophic Earthquake's magnitude 7.6 caused destruction in Pakistan, as There was no proper seismic shallow foundation design in the Peshawar areas of Khyber Pakhtunkhwa Pakistan. And awakened the professionals to mitigate the loss of lives and minimize the damage to properties. Most of the buildings in Peshawar areas are resting on shallow foundations which are just designed for static bearing capacity. Now it needs to include the seismic bearing capacity of such foundations additionally and a design safe structure. Such a problem is considered in this work for Airport office building as a case study in which the available data are used for the design of static and seismic bearing capacities of shallow foundations. In this paper, an isolated foundation of 1mx1mx1m & 2mx2mx1m dimensions are analyzed and used SoFA software for static and dynamic bearing capacity accordingly Euro code 7-5 & 8-5. SoFA is MATLAB-based program. SoFA performs analysis and a design of foundation in Static and Earthquake-bearing capacity. Running the software on data, the result of 1mx1mx1m dimension is given failure in both static & seismic condition, while 2mx2mx1m dimension is satisfied and meets the required design aspect's safe structure and also design is economical.*
KEWORDS: *Seismic & Static bearing capacity, Safe Shallow foundation, MATLAB SoFA software.*

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I. INTRODUCTION

II. PROBLEM OF STATEMENT

The October 8th catastrophic earthquake in 2005 in Azad Kashmir, magnitude 7.5 (Richter Scale), and neighboring areas of Khyber Pakhtunkhwa Province in Pakistan raised awareness among the public and engineering community about designing foundations for earthquake effects. Peshawar is one of the seismic zones classified by the Uniform Building Code 1997, with a soil profile type SD. According to the Revised Seismic Provisions (2007) of Pakistan [1], the area is in Seismic Zone 2B, with peak horizontal ground acceleration ranging from 0.16 to 0.24 g. The October 8, 2005, earthquake destroyed masonry units that were not very well bonded and confined; there was no proper shallow foundation design; and the units were of rubble masonry stones. According to Missouri-Arizona University professors, the roofs in such cases must be supported by at least four RCC columns. RCC columns require footings. Recently in Khyber Pakhtunkhwa, Peshawar, designers used thumb rules and Euro code 7-5 practices for shallow foundation analysis and design, which are uneconomical and unsafe, and most of the private and public buildings in Peshawar rest on shallow foundations that are just designed for static bearing capacity. Now it is a need of the hour to include the seismic or earthquake-bearing capacity of such foundations too, and the design of shallow foundations should be done on this basis in addition to seismic bearing capacity using SoFA software to make them economical and safe structures. In this paper, a shallow foundation (isolated footing) is taken for the airport Office Building as a case study, and SoFA software is used to analyze and design it.

III. INTRODUCTION TO SOFA MATLAB-BASED SOFTWARE

SoFA is a MATLAB-based Computer Software for the Shallow Foundation (Isolated and Strip Footings) Analysis and Design The procedure for designing a shallow foundation comprises numerous verifications; among them, two are bearing capacity and settlement calculations. Advanced computer software utilized in engineering practices is divided into two considerable ways: scientific, which uses empiric formulas, and numeric, which uses finite element models to approach bearing capacity or settlements of footings [2]. SoFA [3] is a MATLAB-based [4] program with a graphical and textural interface. SoFA software was established for earthquake engineering and soil dynamic and earthquake-resistant design of foundations. Factors of safety in this software against bearing capacity failure of the soil are calculated using many formulas from previous literature. For static bearing capacity, Euro code 7, DIN4017 [5], and the old Greek design code EAK2000 are used. Moreover, the literature formulas proposed by Meyerhof [6,7] and Hansen [8] are also included. For bearing capacity under earthquake loads, the Euro code 8 [9]. SoFA software also calculates settlements. SoFA software is given analysis and design for all design approaches implemented in Euro code 7 for static loading conditions and in Euro code 8 for seismic loading conditions. Extended reports of the calculation are given in textural and graphical form.

IV. GETTING STARTED

Many methods are used to calculate the bearing capacity of shallow footings. The procedure for designing a shallow foundation comprises numerous verifications. Several researchers worked on static bearing capacity such as Terzaghi (1943), and Meyerhof (1963) [10]. Shinohara (1960) adopted a pseudo-static approach [11], and afterward, other researchers namely Sarma & Lossifelis (1990), Richards (1993), Budhu & Al-karni (1993) [12], Kumar & Kumar (2003), and Choudhry & Subah Rao (2005) have studied seismic bearing capacity as a problem under vertical load and used limit equilibrium methods to give a solution for seismic bearing capacity [13]. Subah Rao& Choudhry, 2006[14]; Yang,2009; Castelli & Motta,2010[15]; Saada,2011; Farzaneh,2013[16]. All these researchers mentioned upper bound theorem of limit analysis theory for that the solution is exact limiting solution but in generally unsafe estimate of the failure load. In this paper, SOFA MATLAB-based software is used to analyze and design shallow foundation-bearing capacities, such as static and dynamic capacities. Bacha Khan Airport Office Building Peshawar, Khyber Pakhtunkhwa, Pakistan is taken as a case study. In light of the above-mentioned methods and techniques, the SoFA software is run on the data collected from the site for the case study in Peshawar. The data required for this program are tabulated from bore logs. The first 1m x 1m x 1m dimension foundation is taken and put data in SoFA software, the result is a failure, and SoFA software is given a factor of safety of 0.60 in static conditions, which is less than 2.0, and 0.26 in dynamic conditions, which is less than 1.0. The foundation is unsatisfied and failed in both static (Euro code 7-5) and seismic conditions. According to Euro code 8 (EN1998, part 5—Annex F), $\bar{N} \leq 1$, $|\bar{V}| \leq 1$. Then modified and increased the dimension from 1m x 1m x 1m to 2m x 2m x 1m, For the result of 2m x 2m x 1 m, the dimension is safe, and SoFA is given a factor of safety of 2.41 in static conditions, which is greater than 2.0, and in earthquake conditions, 1.45 greater than 1.0, as satisfied by Euro code 8 (EN1998, part 5—Annex F). This paper contains detailed information on the methodology used to analyze and design a shallow foundation for SoFA software. A stepped procedure has been defined with the help of textural and diagrams.

V. METHODOLOGY

The forecasting of bearing capacity of shallow foundation is a very crucial problem in geotechnical engineering, and in the last Fifty years solutions using limit analysis, slip-line, limit equilibrium and recently numerical methods (i.e., finite element and different finite methods) have been developed. And this paper is on SoFA MATLAB-based educational software for shallow foundation analysis and design, which is MATLAB-based software. The data is collected from consultant and Soil tests conducted by the Consultants for Bacha Khan International Airport office building. SoFA MATLAB based software is used to analyzed and designed shallow foundation.

5.1 SOFA MATLAB-BASED SOFTWARE USE

Step 1. The geometry of the problem: Select a rectangular or strip foundation, footing dimensions, Depth of foundation, Depth of water level (you are allowed to set it infinite), footing base inclination, and Soil inclination.

Step 2. Soil Properties: Select a cohesive or cohesionless soil, Select drained or undrained loading conditions, Angle of friction (ϕ), cohesion or undrained shear strength of soil, soil unit weight (γ), and saturated soil unit weight (γsat).

Step.3 Settlement Data: Modulus of elasticity of Soil (E), Poisson's ratio (n), Stratum thickness (H), For cohesive soils, the following are also required, Over Consolidation Ratio (OCR), Initial Voids Ratio (EO), Compression Index / Recompression Index (Cc / Cr).

Step 4. Loads (only static loads are used for a static bearing capacity check): Vertical, horizontal loads and moments, additional surface loads, select the appropriate Design Approach, default is DA2 (DA's are described in Euro code 7) Partial safety factors may be modified at will. - leave Earthquake Design at NO.
Step 5. Loads (only Earthquake loads are used for an earthquake-bearing capacity check): Vertical, horizontal loads and moments, Additional surface loads, select the appropriate Design Approach, default is DA2 (DA's are described in Euro code 7), Partial safety factor may be modified at will. - leave Earthquake Design at YES. For more details putting data in SoFA software See figure: 1.

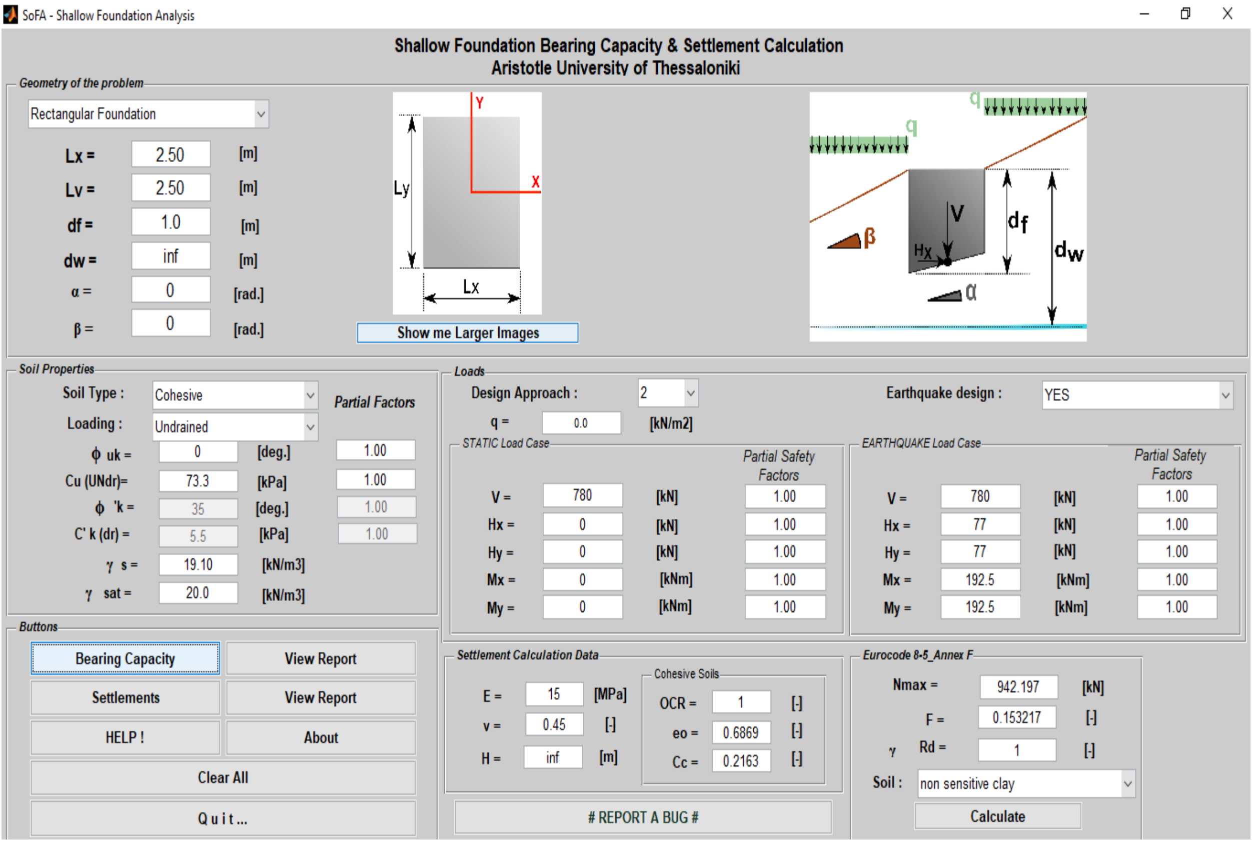

Figure 1: SoFA Environment for Static & Earthquake-bearing capacity of shallow foundation.

5.2 ANALYSIS OF STATIC & EARTHQUAKE BEARING CAPACITY OF 1M X 1M X 1M DIMENSION

The SoFA software is run on the data collected from the site for the Case study airport office building in Peshawar. The Figures 3,4 and 5 is shown that dimension 1m x 1m x 1m is failed, less than required design and did not meet the required design aspects. The dimension will be increased until getting the required design of foundation aspects.

```
Bearing Capacity Report.txt
Shallow Foundation Bearing Capacity
-----------------------------------------------------------------
Kostis Nikolaou (sofa.eng@gmail.com)
Dimitris Pitilakis
Aristotle University of Thessaloniki - 2012
-----------------------------------------------------------------

Geometry of the problem
* Dimentions(dx/dy) = 1.000 x 1.000 [m]
* Depth of foundation (df) = 1.000 [m]
* Depth of water level(dw) =  Inf [m]
* Foundation base inclination(omega) = 0.000 [rad.]
* Soil inclination(beta)             = 0.000 [rad.]

Design Loads - Static Load Case
* Vd  = 780.000 [kN]
* Hdx = 0.000 [kN]
* Hdy = 0.000 [kN]
* Mdx = 0.000 [kNm]
* Mdy = 0.000 [kNm]

Design Loads - Earthquake Load Case
* Ved  = 780.000 [kN]
* Hex = 77.000 [kN]
* Hey = 77.000 [kN]
* Mex = 192.500 [kNm]
* Mey = 192.500 [kNm]

Soil Properties
* Type    = C [C: cohessive  CL: cohesionless]
* Loading= UN [D: drained    UN: undrained]
* phik   =  0.0 [deg.]
* ck   =  5.5 [kPa] -   drained shear strength
* cuk = 73.3 [kPa] - undrained shear strength
* soil Weight = 19.10 [kN/m^3]
=================================================================

Eccentricities (Static Load Case): ex = 0.00  ey = 0.00 [m]
Effective Dimentions:  1.000 x 1.000 [m]
Effective Area:  1.000 [m^2]

-----------------------------------------------------------------
```

Figure 2: Static & Earthquake loads putting for 1m x 1m x 1m dimension (isolated footing)

```
------------------------------------------------------------
Bearing Capacity Check -- Undrained Conditions -- Static Load Case
------------------------------------------------------------

* Eurocode 7 (2004)
 sc=1.200 | ic=1.000 | bc=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 471.214[kN]
 - Vu/1.40 = qu*B*L/1.40 = 336.582[kN] < 780.000 [kN] - NOT ok -
 - FS = qu/N*Aeff = 0.604

* EAK (2000)
 sc=1.200 | ic=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 471.214[kN]
 - Vu/1.40= qu*B*L/1.40 = 336.582[kN] < 780.000 [kN] - NOT ok -
 - FS = qu/N*Aeff = 0.604

* DIN4017 (2006)
 sc=1.200 | ic=1.000 | bc=1.000 | gc=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 471.214[kN]
 - Vu/1.40= qu*B*L/1.40 = 336.582[kN] < 780.000 [kN] - NOT ok -
 - FS = qu/N*Aeff = 0.604

* Meyerhof (1953,1963)
 sc=1.200 | ic=1.000 | dc=1.200 |
 sq=1.000 | iq=1.000 | dq=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 471.214[kN]
 - Vu/1.40= qu*B*L/1.40 = 336.582[kN] < 780.000 [kN] - NOT ok -
 - FS = qu/N*Aeff = 0.604

* Hansen (1970)
 sc=0.000 | ic=0.000 | bc=0.000 | gc=0.000 | dc=0.400 |
 - qu un = 527.467 [kPa]
 - Vu = qu*B*L = 527.467[kN]
 - Vu/1.40= qu*B*L/1.40 = 376.762[kN] < 780.000 [kN] - NOT ok -
 - FS = qu/N*Aeff = 0.676
------------------------------------------------------------
Bearing Capacity Check -- Earthquake Load Case
------------------------------------------------------------
```

Figure 3: Static-bearing capacity of 1m x 1m x 1m dimension (isolated footing)

```
----------------------------------------------------------------
Bearing Capacity Check -- Earthquake Load Case
----------------------------------------------------------------
* EAK (2000)
  sc=1.200 | ic= NaN |
  - qu un =  NaN [kPa]
  - Vu = qu*B*L =  NaN[kN]
  - Vu/1.3= qu*B*L/1.3 =  NaN[kN] < 780.000 [kN]
  - FS = qu/N*Aeff =  NaN

* Eurocode 8 5 (2004)- Annex F(Informative)
   shape factor sc = 1.01
   Ntot = Nmax*L*sc = 192.40
 X direction
   - n = grd*Ned/Ntot = 4.0540
   - v = grd*Ved/Ntot = 0.4002
   - m = grd*Med/(B*Ntot) = 1.0005
   - F = 0.0613
   - c = 99.0000  > 0.00 - NOT ok -
   - SF = 0.1327
 Y direction
   - n = grd*Ned/Ntot = 4.0540
   - v = grd*Ved/Ntot = 0.4002
   - m = grd*Med/(B*Ntot) = 1.0005
   - F = 0.0613
   - c = 99.0000  > 0.00 - NOT ok -
   - SF = 0.1327
```

Figure 4: Earthquake-bearing capacity of 1m x 1m x 1m dimension (isolated footing)

Figures 3 is shown the static-bearing capacity according to EC7 (Euro code), EAK (Greek code), DIN (German code), MEY (Meyerhof) is 336.58 KN but according to HAN (Hansen formula) is 376.76 KN which is less than the required bearing capacity 780 KN on every footing (See figure 3 and 4 mentioned design is NOT OK). And figure 4 is shown that the Earthquake-bearing capacity according to Euro code 8 (2004) – Annex F in X-direction and Y-direction is 0.132 (factor of safety) which is also less than the required design aspects $\bar{N} \leq 1$, $|\bar{V}| \leq 1$. Figure 5 is shown safety factors in static-bearing capcity 0.60 while requirement is 2.0 and in earthquake-bearing capacity is 0.20 which is less than 1.0, the dimension is failed and it's to be increased.

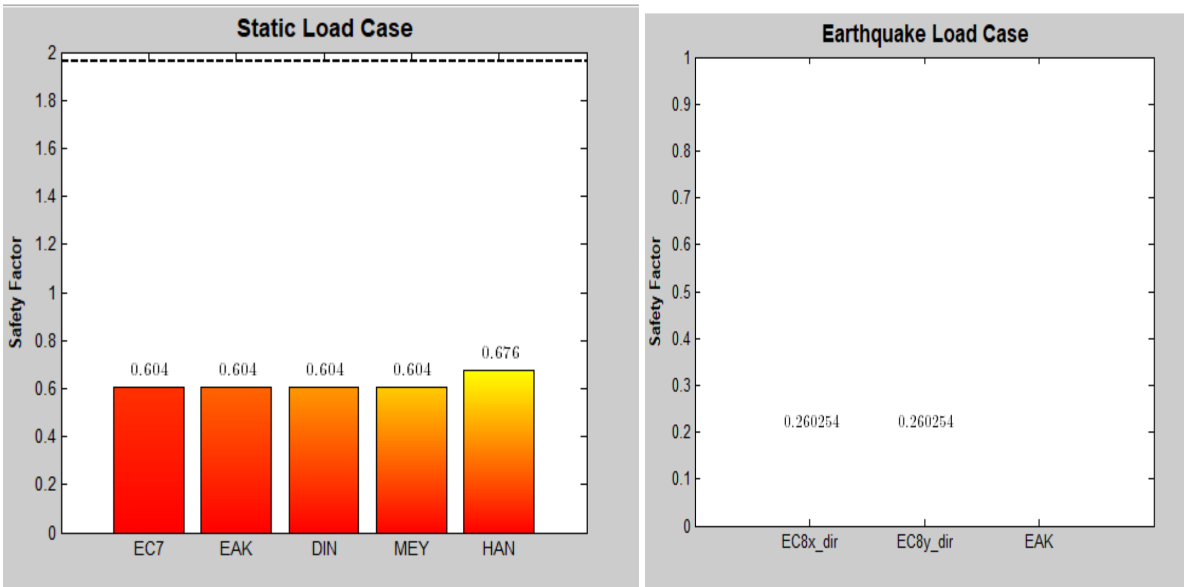

Figure 5: Safety factor of static & Earthquake-bearing capacity 1m x 1m x 1m dimension (isolated footing)

5.3 ANALYSIS OF STATIC & EARTHQUAKE-BEARING CAPACITY OF 2M X 2M X 1M DIMENSION

Again, increased the dimension from 1mx1mx1m to 2mx2mx1m, and the SoFA software is run on the data collected from the site for the Case study airport office building in Peshawar. The figure 7,8 and 9 is shown that dimension 2m x 2m x 1m is satisfied with safety and economy, more than required design and meet the desire design aspects. The dimension has no failure and has gotten required design of foundation. These dimensions are safe and economical.

```
Bearing Capacity Report.txt
Shallow Foundation Bearing Capacity
--------------------------------------------------------------
Kostis Nikolaou (sofa.eng@gmail.com)
Dimitris Pitilakis
Aristotle University of Thessaloniki - 2012
--------------------------------------------------------------

Geometry of the problem
* Dimentions(dx/dy) = 2.000 x 2.000 [m]
* Depth of foundation (df) = 1.000 [m]
* Depth of water level(dw) =  Inf [m]
* Foundation base inclination(omega) = 0.000 [rad.]
* Soil inclination(beta)             = 0.000 [rad.]

Design Loads - Static Load Case
* Vd  = 780.000 [kN]
* Hdx = 0.000 [kN]
* Hdy = 0.000 [kN]
* Mdx = 0.000 [kNm]
* Mdy = 0.000 [kNm]

Design Loads - Earthquake Load Case
* Ved  = 780.000 [kN]
* Hex = 77.000 [kN]
* Hey = 77.000 [kN]
* Mex = 192.500 [kNm]
* Mey = 192.500 [kNm]

Soil Properties
* Type    = C [C: cohessive  CL: cohesionless]
* Loading= UN [D: drained    UN: undrained]
* phik   =  0.0 [deg.]
* ck   =   5.5 [kPa] -   drained shear strength
* cuk = 73.3 [kPa] - undrained shear strength
* soil Weight = 19.10 [kN/m^3]
==============================================================

Eccentricities (Static Load Case): ex = 0.00  ey = 0.00 [m]
Effective Dimentions:  2.000 x 2.000 [m]
Effective Area:  4.000 [m^2]

--------------------------------------------------------------
```

Figure 6: Static & Earthquake loads putting for 2m x 2m x 1m dimension (isolated footing)

```
------------------------------------------------------------
Bearing Capacity Check -- Undrained Conditions -- Static Load Case
------------------------------------------------------------

* Eurocode 7 (2004)
 sc=1.200 | ic=1.000 | bc=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 1884.858[kN]
 - Vu/1.40 = qu*B*L/1.40 = 1346.327[kN] > 780.000 [kN] - ok -
 - FS = qu/N*Aeff = 2.416

* EAK (2000)
 sc=1.200 | ic=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 1884.858[kN]
 - Vu/1.40= qu*B*L/1.40 = 1346.327[kN] > 780.000 [kN] - ok -
 - FS = qu/N*Aeff = 2.416

* DIN4017 (2006)
 sc=1.200 | ic=1.000 | bc=1.000 | gc=1.000 |
 - qu un = 471.214 [kPa]
 - Vu = qu*B*L = 1884.858[kN]
 - Vu/1.40= qu*B*L/1.40 = 1346.327[kN] > 780.000 [kN] - ok -
 - FS = qu/N*Aeff = 2.416

* Meyerhof (1953,1963)
 sc=1.200 | ic=1.000 | dc=1.100 |
 sq=1.000 | iq=1.000 | dq=1.000 |
 - qu un = 433.538 [kPa]
 - Vu = qu*B*L = 1734.153[kN]
 - Vu/1.40= qu*B*L/1.40 = 1238.681[kN] > 780.000 [kN] - ok -
 - FS = qu/N*Aeff = 2.223

* Hansen (1970)
 sc=0.000 | ic=0.000 | bc=0.000 | gc=0.000 | dc=0.200 |
 - qu un = 452.114 [kPa]
 - Vu = qu*B*L = 1808.458[kN]
 - Vu/1.40= qu*B*L/1.40 = 1291.755[kN] > 780.000 [kN] - ok -
 - FS = qu/N*Aeff = 2.319
------------------------------------------------------------
```

Figure 7: Static-bearing capacity of 2m x 2m x 1m dimension (isolated footing)

```
-----------------------------------------------
* EAK (2000)
 sc=1.200 | ic= NaN |
 - qu un =  NaN [kPa]
 - Vu = qu*B*L =  NaN[kN]
 - Vu/1.3= qu*B*L/1.3 =  NaN[kN] < 780.000 [kN]
 - FS = qu/N*Aeff =  NaN

* Eurocode 8 5 (2004)- Annex F(Informative)
  shape factor sc = 1.22
  Ntot = Nmax*L*sc = 1379.76
 X direction
  - n = grd*Ned/Ntot = 0.5653
  - v = grd*Ved/Ntot = 0.0558
  - m = grd*Med/(B*Ntot) = 0.0698
  - F = 0.1226
  - c = -0.6520  < 0.00 - ok -
  - SF = 1.3281
 Y direction
  - n = grd*Ned/Ntot = 0.5653
  - v = grd*Ved/Ntot = 0.0558
  - m = grd*Med/(B*Ntot) = 0.0698
  - F = 0.1226
  - c = -0.6520  < 0.00 - ok -
  - SF = 1.3281
```

Figure 8: Earthquake-bearing capacity of 2m x 2m x 1m dimension (isolated footing)

Figures 7 is shown that the static-bearing capacity according to EC7 (Euro code), EAK (Greek code), DIN (German code) is 1346.32 KN and MEY (Meyerhof) is 1238.68 KN but according to HAN (Hansen formula) bearing capcity is 1291.75 KN, which is greater than the required bearing capacity 780 KN on every footing. And figure 8 is shown the Earthquake-bearing capacity according Euro code 8 (2004) – Annex F in X-direction and Y-direction is 1.32 (factor of safety) which is also greater than the required design aspects $\bar{N} \le 1$, $|\bar{V}| \le 1$ (See figure 7 and 8 mentioned design is OK). Figure 9 is shown that safety factors in static-bearing capcity 2.41 but requirement is 2.0, so the dimension is okay with requirement of design and in earthquake-bearing capacity is 1.45 which is greater than 1.0, the dimension is met with required design aspects.

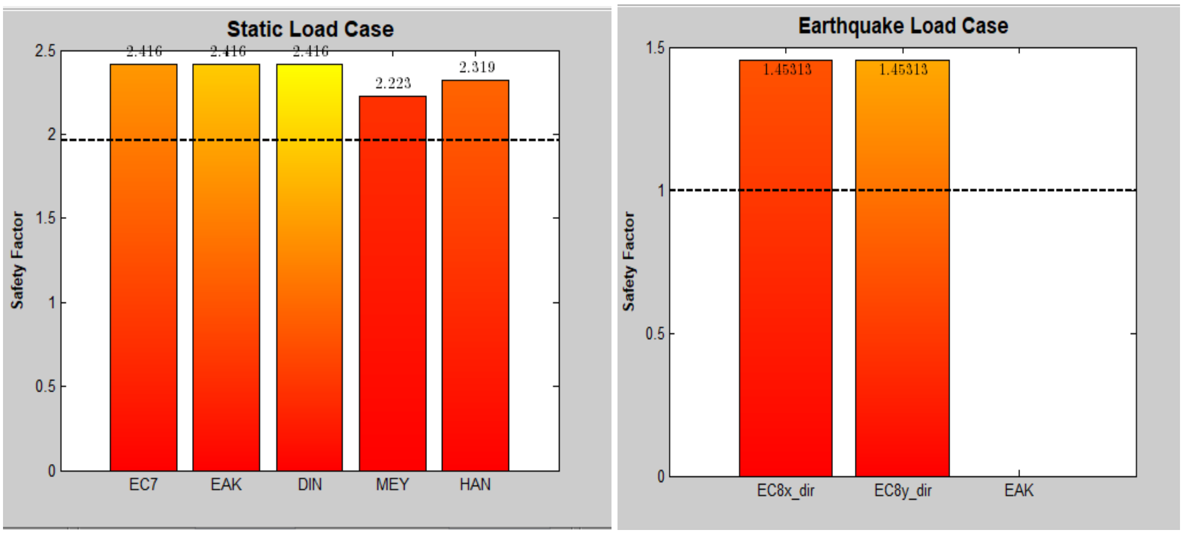

Figure 9: Safety factor of static & Earthquake-bearing capacity 2m x 2m x 1m dimension (isolated footing)

VI. RESULTS AND DISCUSSION

The data based on average unconfined compressive strength of 1.46 kg/cm2 of all the boreholes for this size of isolated footing are input in the SoFA program. The SoFA software is run on the data collected from the site for Case study airport office building in Peshawar. For the first analysis 1m x 1m x 1m dimension shallow foundation is taken, the figure 3 and 4 show the results of allowable bearing capacity for the all the codes mentioned earlier. The bar diagram in figure 3, 4 and 5 shows comparison of the all the codes bearing capacity which is less than the required bearing pressure, so the foundation is failed and did not meet the desire foundation design. And SoFA software is given a factor of safety of 0.60 (see figure 5) in static conditions, which is less than 2.0, and 0.26 in dynamic conditions, which is less than 1.0. The foundation is unsatisfied and did not meet the requirement of design aspect in both static (Euro code 7-5) and seismic conditions, according to Euro code 8 (EN1998, part 5—Annex F), $\bar{N} \le 1$, $|\bar{V}| \le 1$. It is found that the foundation is to be increased. Again, Increased the dimension from 1m x 1m x 1m to 2m x 2m x 1m. For the result of 2m x 2m x 1m, now the dimension is safe, and SoFA is given safety factor 2.41 (see figure 9) in static conditions, which is greater than 2.0, and in earthquake conditions, 1.45 greater than 1.0, as satisfied by Euro code 8 (EN1998, part 5—Annex F). This method is so easy to evaluate and design seismic bearing-capacity for the designers of Peshawar Pakistan. In future the designers of KPK Peshawar, Pakistan can include the seismic evaluation to mitigate the risk of earthquake such as loss of lives and minimize damage to properties in Khyber Pakhtunkhwa, Pakistan.

VII. CONCLUSION

Recently in Khyber Pakhtunkhwa Civil Engineering designers use thumb rules Euro code practices for shallow foundation analysis and design, which are unsafe & uneconomical. And Most of the private and public buildings in Peshawar areas are resting on shallow foundations which are designed just for static bearing capacity. Now it is needed to include the Seismic or Earthquake bearing capacity of such foundations additionally and design of shallow foundation using SoFA MATLAB-based computer software to mitigate earthquake risk like property damaging & most of important loss of lives, also to make economical and safe structures. This work also introduces a workable MATLAB-based software for economical and safe shallow foundation structural analysis and design. And The purposes have been specified as follows:

- Understanding Analysis and design of the shallow foundation (Static & Seismic bearing capacity) on SoFA MATALAB-based computer software.
- Mitigate Seismic risk such as loss of lives and minimize property damage in Khyber Pakhtunkhwa, Pakistan.
- Earthquake-Bearing capacity of shallow foundations on SoFA MATLAB-based software with safe and Economical structures in Khyber Pakhtunkhwa, Pakistan.
- Static Bearing capacity of shallow foundations on SoFA MATLAB-based software with safe and Economical structures in Khyber Pakhtunkhwa, Pakistan.

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