# Using the Finite Element Analysis of Digitalized Photos to Evaluate the Quality of Concrete

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**Abstract:** The characterization of concrete on macrostructure based evaluation using the numerical techniques is still limited because modeling the concrete as a single-phase material. Therefore, misunderstanding the actual behavior of the concrete elements is the end result. On the other hand, microstructural analysis are still qualitative technique and very difficult to be used to assess the mechanical characteristics of the concrete. The foregoing difficulties motivated researchers to seek new concepts to maximize the benefits from using the finite element analysis. The Digital Image Analysis has been used to identify aggregate quality and gradation. Recently, attempts are carried out torelate the output of the digital image processing to the numerical analysis. Concrete cylindrical specimens of different mixes that manually or mechanically compacted were used to implement the experimental program. The concrete specimens were saw cut and photographed using digital camera. The photos were treated using computer software to be transferred to the AUTOCAD program as two layers; cement mortar and aggregate. Then, the AUTOCAD files were exported to the finite element analysis software SAP2000 to verify the influence of the aggregate type and the method of compaction on the quality and the mechanical properties of the concrete mixes. The results showed that linking the output data of the digital image processing to the finite element analysis led to identify the concrete as a multiphase layers system and consequently, the finite element program succeeded to predict the location of failure inside the system ( in the cement mortar, the aggregate, or at the interface). Also, the finite element analysis succeeded to distinguish among concrete mixes that contained gravel or dolomite aggregates which were compacted using manual or mechanical compaction.
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## 1. Introduction

Modeling the concrete as a single-phase material in the finite element analysis will not lead to understand the actual behavior of the structure of mixes(1,2). So, researchers are seeking for an approach to identify the composite material as coarse aggregate immersed randomly in the cement mortar (3,4). The Digital Image Analysis (DIA) is usually used to implement qualitative and quantitative evaluation (5,6). It is believed that the DIA can be an effective technique to express the concrete as a double-phase material (7,8). Relating the DIA output to the finite element analysis seems to be the required approach and should be verified (9, 10). The combined method should consider the following:

1-The combined method can easily and thoroughly explain the mechanisms of failure of the concrete.
2-The method should easily relate the microstructure characteristics to the mechanical properties of the concrete.
3-The method should be easily implemented and should not need special equipment difficult to interpret.

## 2. Objectives

The presented research work aims to seek the following:

1- Finding the method of linking the results of the digital image processing to the finite element program.
2- Using the combined method to verifying the role of aggregate type and compaction method on the concrete compressive strength.
3- Using the finite element to find the most probable place of failure inside the concrete wherever inside the aggregate, the mortar, or at the interface.

## 3. Materials characterization and modeling:

The experimental and analytical programs were implemented using 24 concrete cylinders of 100mm diameter and 200mm long which were casted and cured in water for 28 days. Sixteen cylinders were kept for implementing the compression and indirect tension tests and eight cylinders were used to carry out the DIA. Photos from (1) to (3) and Figure (1) show the implemented experimental and analytical programs. The compressive and tensile strengths are presented in Table (1).

Four concrete cylinders which contained gravel were divided into two groups. The concrete cylinders in the first group were manually compacted while in the second group they were mechanically compacted. The first cylinder in each groupwas saw cut longitudinally through the axis passing the center of

the cylinder and it was photographed using digital camera of high resolution set at a fixed distance of 1.0m. Photo (1) and Figure (1) explains the experimental procedure. The second cylinder in each group was saw-cut horizontally at top (20mm from top surface) and mid-sections as shown in Photo (2). The cross sections were photographed as explained above. The image was converted from color image to white and black image. The specimen was cut out from the whole image using a program called "Photo Effect", and then it was saved in "TIFF" extension. The image was analyzed by a new software called "VEXTRACTOR DEMO'' version 5 to convert the image from "JPG" to "DXF" to treat it as AUTOCAD drawing. The Digital image processing was similarly implemented on the other four cylinders which contained dolomite. The finite element analysis was carried out on four vertical sections and eight horizontal sections.

The shell element used in modeling the specimens was defined as full shell elements. The Material properties were linear elastic and isotropic. The isotropic mechanical and thermal properties relating strain to stress and temperature change were as follows:

**E1 :** Young's modulus of elasticity,
**μ12:** Poisson's ratio,
**G1 :** Shear modulus, and
**α1 :** Coefficient of thermal expansion.

This relationship holds regardless of the orientation of the Material local axes 1, 2, and 3. Table (2)summarizes the values of the specified characteristics used in the finite element program. The specimens were modified in AUTOCAD by drawing a 3D-face element in the bottom left corner in a layer nominated "cement mortar" and arrayed to the whole image. Internal 3D-face element has been stretched to the perimeter of the aggregate and converted to a new layer nominated "aggregate". The drawing was saved in "DXF" extension and imported in SAP 2000 in two steps. In the first step, the "aggregate" layer was imported and defined as shown in Table **(**1**)**. After that, the "cement paste" layer was imported and defined as given in Table **(**1**)**.The reference specimen was modeled using shell element. The specimen is divided into 3200 elements of dimensions (2.5mm × 2.5mm).

**4. Failure criterion and definitions:**

The concrete wasconsidered ultimately failed if the induced tensile stress is more than 30kg/cm$^2$.It is assumed that full bond at the interface between the aggregate and the cement paste is existed. Two levels of comparison are made based on the induced normal stress S11. The normal stress S11 is defined as the normal stress induced in the direction perpendicular to the direction of the applied load. The compressive and tensile strength results are shown in Table (1). The compressive strength of manually compacted concrete specimens contained gravel is taken as reference to calculate the load of each node as follows:

Compressive load=$\mathbf{f_{cu}}$(kg/cm$^2$)=250kg/cm$^2$
The shell element is divided to 3200 elements of dimensions (2.5mm × 2.5mm)
Load per each node =250×(0.25×0.25)=15.625kg

**5. Results and analysis:**

**5.1Modeling the concrete as a single-phase material:**

Figure (2) shows the contour of normal stress S11of the vertical section passing longitudinal axis of a single phase material. It is clear that modeling the concrete as a single-phase material will not identify the location of failure wherever occurs in the mortar, the aggregate, or at the interface. Table (3) shows the computed normal stress S11 at the longitudinal axis passing the centroid of the vertical plane of the photo where compressive stresses were observed at top and bottom while tensile stresses were observed almost at the middle third of the photo. The tensile stresses ranged from 0.17kg/cm$^2$ to 3.63kg/cm$^2$.

**5.2Modeling the concrete as adouble-phase material (longitudinal section):**

The contour of normal stress S11of the vertical sectionofconcrete modeled as double-phase material is shown in Figures from (3) to (6). The values of normal stress S11 were computed and recorded in Tables (4)and(5).

**5.2.1 Effect of modeling procedure:**

Table (4) shows the normal stresses S11 at the longitudinal axis passing the centroid of the vertical plane of the photo of mixes contained gravel and compacted either manually or mechanically. The induced stress depends mainly on the phase of the material. The results inTable (4) indicated that the mortar and the interface are subjected to tensile stresses while the aggregates are subjected to compressive stresses. Figure (7) indicated the significant influence of modeling technique on the induced stresses and consequently the structural behavior of the material when exposed to external loads. As shown in Figure (8), modeling the concrete as double-phase material leads to identify the actual stress conditions, tension or compression wherever inside the mortar, the aggregate or at the interface. Similar observations were existed when concerning the mechanically compacted concrete specimen. The difference was in the absolute values of the normal stress S11.

**5.2.2 Effect of compaction method on the induced normalstress S11:**

As shown in Table (4) of manually compacted concrete mix, the tensile stress S11 induced in the mortar at the middle third ranged from 11.39kg/cm$^2$to

58.80kg/cm$^2$. In case of mechanical compaction, the tensile stress S11 in the mortar at the middle third ranged from 8.30kg/cm$^2$ to 45.00kg/cm$^2$. Similarly, The tensile stress S11 at the interface of the middle third ranged from 13.37kg/cm$^2$ to 49.40kg/cm$^2$, while it ranged from 5.40kg/cm$^2$ to 16.75kg/cm$^2$ in case of mechanical compaction. The compressive stress S11 in the aggregate ranged from 29.50kg/cm$^2$ to 65.30kg/cm$^2$ in case of manual compaction, while it ranged from 5.60kg/cm$^2$ to 31.90kg/cm$^2$ in case of mechanical compaction. The results in Table (5) show that similar trends were notedfor the concrete specimen of mix containing dolomiteand the differences were in the absolute values of the normal stress S11. The results indicated that compacted concrete mix using the vibrator leads to induce lower normal stresses when compared to the manually compacted concrete mix.

**5.2.3 Effect of aggregate type on the induced normalstress S11:**

Figure (7) shows the normal stress S11 at the longitudinal axes passing the planes of the centroid of the photos of mixes containedeither gravel or dolomite. The mix that contained gravel showed relatively higher normal stress S11 when compared to that contained dolomite. However, the effect of the type of the aggregate was not clear comparing to the method of compaction. Special treatment of the boundary conditions may be needed to show up the significant effect of the aggregate type. In case of mechanical compaction, the results showed that significant increase in the induced compressive stresses in the gravel aggregates when compared tothose induced in the dolomite aggregates. Similar trend was observed in case of the tensile stresses induced in the cement mortar while slight increase in the tensile stresses were observed at the interface of the gravel aggregates when compared to the tensile stresses at the interface of the dolomite aggregates.

**5.2.4 Normal stress S11 at the transverseaxis of concrete specimen:**

Table (6) shows the computed normal stress S11 in the transverse direction through the axis passing the centroid of the photo. The sections are subjected to tensile stresses of minimum value 0.04kg/cm$^2$at the edge and maximum value 2.84kg/cm$^2$at the center. Tables (7) and (8) show the normal stress S11 in the transverse axis passing the centroid of the photo when the concrete is modeled as double phase material. It was clear that relatively higher stress value was obtained for the case of the gravel aggregate when compared to the value of the dolomite aggregate. The mechanically compacted mixes showed relatively smaller normal stress values with respect to the manually compacted mixes. The normal stress values are considered at the middle third of the photo to avoid the undesirable effect of the boundary conditions at bottom. It has been noticed that the type of the aggregate hada slight effect on the induced normal stress S11 when compared to the effect of the compaction type. This may be due to modeling the interface conditions as a case of fully bonded aggregate to the mortar. However, the finite element analysis succeeded to distinguish between the two aggregate types due to modeling the concrete as double-phase material.

**6.Normal stress S11for sections at top and mid of the photo:**

**6.1 Modeling the concrete asa single-phase material:**

Table (9) and Figure(9)show the normal stress S11 at the vertical and horizontal axes passing the centroid of the photo. The induced tensile stress ranged from 14.66kg/cm$^2$ to 19.01kg/cm$^2$ and the maximum value has been observed at the center. High compressive stresses are observed at top and bottom. The normal stress S11 at the horizontal section passing the centroid ranged from 0.095 kg/cm2 at the edge to 18.99kg/cm$^2$ at center. Figure (9)showed that it was impossible to identify the nature of the failure whereverit wasin the mortar, at the interface or in the aggregate.

**6.2 Modeling the concrete as a double-phase material (circular sections):**

**6.2.1 Top section for mix contained gravel:**

Table (10) and Figures from (10) to (11) show the normal stress S11 at the vertical axis of manually and mechanically compacted specimens respectively. In case of manual compaction, the tensile stress at the middle third ranged from 11.13kg/cm$^2$ to 32.56kg/cm$^2$ while it ranged from 10.15kg/cm$^2$ to 28.03kg/cm$^2$ in case of mechanical compaction. Slight reduction in the induced stress S11 was observed in case of mechanical compaction. The maximum tensile stress in the mortar, at the interface, and in the aggregatewas 25.75kg/cm$^2$ and 24.11kg/cm$^2$, and 32.56kg/cm$^2$ for the case manual compaction while it was 29.39kg/cm$^2$, 21.11kg/cm$^2$, and 28.03kg/cm$^2$ for the case of mechanical compaction.

The normal stress S11 at the horizontal axis passing the centroid showed that manual compaction led to higher stress with respect to the case of mechanical compaction. Table (11)presents the induced normal stresses in the mortar, the aggregate, and at the interface. For the case of manual compaction the maximum normal stressin the mortar, at the interface, and in the aggregate was 30.33kg/cm$^2$, 21.67kg/cm$^2$, and 26.11kg/cm$^2$ while they were 23.85kg/cm$^2$, 26.45kg/cm$^2$, and 21.87kg/cm$^2$ for the case of mechanical compaction respectively.

**6.2.2 Top section of mix containsdolomite:**

Table (12) and Figures from (12) to (13) show

the normal stress S11 at the top of the vertical sections ofmanually and mechanically compacted specimens respectively. In case of manual compaction, the tensile stress at the middle third ranged from 19.10kg/cm$^2$ to 32.90kg/cm$^2$ while it ranged from 13.11kg/cm$^2$ to 23.25kg/cm$^2$ in case of mechanical compaction. Significant reduction in the induced stress S11 was observed in case of mechanical compaction. The maximum tensile stress in the mortar was 19.55kg/cm$^2$ and 19.40kg/cm$^2$ for manual and mechanical compaction respectively while it was 20.60kg/cm$^2$ and 23.25kg/cm$^2$ at the interface.

For the top section, the results of the normal stress S11 at the horizontal section passing the centroid show that manual compaction led to higher stress with respect to the case of mechanical compaction. Table (13) shows the induced normal stress in the mortar, aggregate, and at the interface. For the case of manual compaction, the maximum normal stressesin the mortar, at the interface, and the aggregate were 28.72kg/cm$^2$, 14.60kg/cm$^2$, and 23.44kg/cm$^2$ while they were 19.45kg/cm$^2$, 26.45kg/cm$^2$, and 27.75kg/cm$^2$ for the case of mechanical compaction respectively. Figures (13) and (14)show that the induced stress in case of mechanical compaction was lower than that induced in case of manual compaction.

**6.2.3 Mid- sectionof mix contains gravel:**

Table (14) and Figures from (15) to (16)show the normal stress S11 of the vertical axis at mid-sections manually and mechanically compacted specimens respectively. In case of manual compaction, the tensile stress at the middle third ranged from 20.95kg/cm$^2$ to 34.95kg/cm$^2$ while it ranged from 10.33kg/cm$^2$ to 26.01kg/cm$^2$ in case of mechanical compaction. Significant reduction in the induced stress S11 was observed in case of mechanical compaction. The maximum tensile stress in the mortar was 34.95kg/cm$^2$ and 20.44kg/cm$^2$ for manual and mechanical compaction respectively while it was 24.98kg/cm$^2$ and 26.01kg/cm$^2$ at the interface.

For the mid-sections, the results of the normal stress s11 at the horizontal axis passing the centroid show that manual compaction led to higher stress with respect to the case of mechanical compaction. Table (15) presents the normal stress induced in the mortar, at the interface, and the in aggregate. For the case of manual compaction the maximum normal stressesin the mortar, at the interface, and in the aggregate were 30.02kg/cm$^2$, 25.19kg/cm$^2$, and 14.63kg/cm$^2$ while they were26.10kg/cm$^2$, 18.37kg/cm$^2$, and 13.74kg/cm$^2$ for the case of mechanical compaction respectively.

**6.2.4 Mid- section of mix contains dolomite:**

Table (16)shows the normal stress S11 of the vertical axis at mid-sections of manually and mechanically compacted specimens respectively. In case of manual compaction, the tensile stress at the middle third ranged from 18.00kg/cm$^2$ to 32.25kg/cm$^2$ while it ranged from 13.65kg/cm$^2$ to 25.33kg/cm$^2$ in case of mechanical compaction. Significant reduction in the induced stress S11 was observed in case of mechanical compaction. The maximum tensile stress in the mortar was 32.25kg/cm$^2$ and 20.24kg/cm$^2$ for manual and mechanical compaction respectively while it was 21.27kg/cm$^2$ and 25.33kg/cm$^2$ at the interface.

For the mid-sections, the results of the normal stress S11 at the horizontal axis passing the centroid show that manual compaction led to higher stress with respect to the case of mechanical compaction. Table (17) presents the normal stress induced in the mortar, at the interface, and the in aggregate. For the case of manual compaction, the maximum normal stressesin the mortar, at the interface, and in the aggregate were 17.57kg/cm$^2$, 24.11kg/cm$^2$, and 21.60kg/cm$^2$ while they were 20.22kg/cm$^2$, 17.11kg/cm$^2$, and 21.75 kg/cm$^2$ for the case of mechanical compaction respectively. Figures (17) and (18)show that the normal stress induced in the dolomite is significantly lower with respect to that induced in the gravel. The observation has been noticed for both manual and mechanical compaction. The same observations have been recorded when concerning the vertical and horizontal sections at the mid-section.

**7. Summary and Conclusions:**

It is clear from the conducted research work the potential of modeling the material as a multilayer system. Using a single value of the modulus of elasticity which nominated the modulus of elasticity of concrete as input data in the finite element analysis can only predict the induced stresses and strains but it will not lead to specify the location of failure inside the multilayer system. However, the values and distribution of the induced normal stress in case of modeling the concrete as a double-phase material are completely different from the case of modeling it a single-phase material. Identifying the moduli of elasticity of the layers of the system in the finite element analysis by using the DIA technique can establish a new criterion of design by predicting the location of failure. As shown in the conducted research work, the most probable locations of failure were at the interface or in the mortar. This should be further supported by implementing a comprehensive statistical analysis. As verification, the finite element analysis of the photos succeeds to distinguish among the normal stresses S11 induced in the concrete specimens of mixes which contained gravel or dolomite aggregate. It also analytically explains the influence of the compaction method in terms of inducing different stresses at the top and mid sections of concrete specimen made of the same concrete mix.

**Table 1: Compressive and tensile strength of concrete specimens**

| Aggregate type | Compaction method | Compressive strength (kg/cm$^2$) | Tensile strength (kg/cm$^2$) |
|---|---|---|---|
| Gravel | Manual | 250 | 30 |
| | Mechanical | 280 | 31.7 |
| Dolomite | Manual | 300 | 32.86 |
| | Mechanical | 340 | 34.98 |

**Table 2: Properties of the materials**

| Property | Gravel | Dolomite | Cement Paste |
|---|---|---|---|
| Mass per unit volume (kg/cm$^3$) | 1.6E-06 | 1.6E-06 | 2.4E-06 |
| Wight per unit volume (kg/cm$^3$) | 1.6E-03 | 1.6E-03 | 2.4E-03 |
| Modulus of elasticity (kg/cm$^2$) | 5.5E06 | 5.5E06 | 2E06 |
| Poisson's ratio | 0.15 | 0.14 | 0.25 |
| Coefficient of thermal expansion | 8.1E-06 | 8.1E-06 | 9.9E-06 |

**Table 3: Contour of normal stress (S11) at the longitudinal axis of concrete specimen modeled as a single-phase material**

| Stress location | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|
| 1 | -0.660 | CEMENT | COMP |
| 2 | -0.625 | CEMENT | COMP |
| 3 | -0.580 | CEMENT | COMP |
| 4 | -0.530 | CEMENT | COMP |
| 5 | -0.510 | CEMENT | COMP |
| 6 | -0.460 | CEMENT | COMP |
| 7 | -0.360 | CEMENT | COMP |
| 8 | -0.250 | CEMENT | COMP |
| 9 | -0.150 | CEMENT | COMP |
| 10 | -0.100 | CEMENT | COMP |
| 11 | 0.170 | CEMENT | TEN |
| 12 | 0.3500 | CEMENT | TEN |
| 13 | 0.560 | CEMENT | TEN |
| 14 | 0.930 | CEMENT | TEN |
| 15 | 1.230 | CEMENT | TEN |
| 16 | 1.550 | CEMENT | TEN |
| 17 | 1.730 | CEMENT | TEN |
| 18 | 2.280 | CEMENT | TEN |
| 19 | 2.460 | CEMENT | TEN |
| 20 | 2.840 | CEMENT | TEN |
| 21 | 3.020 | CEMENT | TEN |
| 22 | 3.550 | CEMENT | TEN |
| 23 | 3.630 | CEMENT | TEN |
| 24 | 3.580 | CEMENT | TEN |
| 25 | 3.270 | CEMENT | TEN |
| 26 | 2.550 | CEMENT | TEN |
| 27 | 1.300 | CEMENT | TEN |
| 28 | 0.465 | CEMENT | TEN |
| 29 | -1.900 | CEMENT | COMP |
| 30 | -3.600 | CEMENT | COMP |
| 31 | -5.500 | CEMENT | COMP |
| 32 | -10.400 | CEMENT | COMP |
| 33 | -20.870 | CEMENT | COMP |
| 34 | -35.960 | CEMENT | COMP |
| 35 | -64.080 | CEMENT | COMP |
| 36 | -72.480 | CEMENT | COMP |
| 37 | -90.590 | CEMENT | COMP |
| 38 | -109.960 | CEMENT | COMP |
| 39 | -129.950 | CEMENT | COMP |
| 40 | -140.39 | CEMENT | COMP |

**Table 4: Normal stress (S11) at the longitudinal axis of concrete contained gravel and modeled as a double-phase material**

| tress location | Stress (kg/cm$^2$) | Location | Type | Stress kg/cm$^2$ | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 115.240 | CEMENT | TEN | 98.400 | SURFACE | TEN |
| 2 | -32.040 | AGG | COMP | 15.300 | INTERFACE | TEN |
| 3 | -18.020 | AGG | COMP | 2.200 | INTERFACE | TEN |
| 4 | 20.090 | INTERFACE | TEN | -5.600 | AGG | COMP |
| 5 | 40.088 | INTERFACE | TEN | 17.500 | CEMENT | TEN |
| 6 | 32.190 | CEMENT | TEN | -19.000 | AGG | COMP |
| 7 | 12.480 | CEMENT | TEN | -14.500 | AGG | COMP |
| 8 | 23.090 | CEMENT | TEN | 5.900 | CEMENT | TEN |
| 9 | 10.820 | CEMENT | TEN | 8.500 | INTERFACE | TEN |
| 10 | 9.600 | INTERFACE | TEN | -31.900 | AGG | COMP |
| 11 | -46.000 | AGG | COMP | -25.400 | AGG | COMP |
| 12 | -55.800 | AGG | COMP | 5.400 | INTERFACE | TEN |
| 13 | -29.500 | AGG | COMP | 9.400 | CEMENT | TEN |
| 14 | 29.580 | INTERFACE | TEN | 15.150 | CEMENT | TEN |
| 15 | 21.5500 | CEMENT | TEN | 15.110 | CEMENT | TEN |
| 16 | -12.500 | AGG | COM | 8.140 | INTERFACE | TEN |
| 17 | 38.150 | CEMENT | TEN | 8.300 | CEMENT | TEN |
| 18 | 35.630 | INTERFACE | TEN | 4.190 | INTERFACE | TEN |
| 19 | -26.900 | AGG | COMP | -10.700 | AGG | COMP |
| 20 | -25.130 | AGG | COMP | -7.900 | AGG | COMP |
| 21 | 33.870 | CEMENT | TEN | -20.000 | AGG | COMP |
| 22 | 25.170 | INTERFACE | TEN | 16.750 | INTERFACE | TEN |
| 23 | 25.900 | CEMENT | TEN | 45.000 | CEMENT | TEN |
| 24 | 11.390 | CEMENT | TEN | -14.000 | AGG | COM |
| 25 | 13.370 | INTERFACE | TEN | 19.890 | AGG | TEN |
| 26 | -19.880 | AGG | COMP | -11.500 | AGG | COMP |
| 27 | 41.700 | CEMENT | TEN | 10.100 | INTERFACE | TEN |
| 28 | 17.900 | CEMENT | TEN | 1.800 | INTERFACE | TEN |
| 29 | 49.400 | INTERFACE | TEN | -13.700 | CEMENT | COMP |
| 30 | 39.500 | INTERFACE | TEN | 2.100 | CEMENT | TEN |
| 31 | 58.800 | CEMENT | TEN | -80.000 | CEMENT | COMP |
| 32 | -65.300 | AGG | COMP | 98.400 | SURFACE | TEN |
| 33 | 19.020 | INTERFACE | TEN | 15.300 | INTERFACE | TEN |
| 34 | -4.060 | AGG | COMP | 2.200 | INTERFACE | TEN |
| 35 | -106.900 | AGG | COMP | -5.600 | AGG | COMP |
| 36 | -72.400 | AGG | COMP | 17.500 | CEMENT | TEN |
| 37 | 24.500 | INTERFACE | TEN | -19.000 | AGG | COMP |
| 38 | 27.800 | INTERFACE | TEN | -14.500 | AGG | COMP |
| 39 | 85.370 | CEMENT | TEN | 5.900 | CEMENT | TEN |
| 40 | 100.670 | CEMENT | TEN | 8.500 | INTERFACE | TEN |

**Table 5: Normal stress (S11) at the longitudinal axis of concrete contained dolomiteand modeled as a double-phase material**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -105.240 | AGG | COMP | -94.200 | SURFACE | COMP |
| 2 | 30.110 | CEMENT | TEN | 12.100 | INTERFACE | TEN |
| 3 | 16.020 | INTERFACE | TEN | 2.100 | AGG | TEN |
| 4 | -19.310 | AGG | COMP | -3.900 | AGG | COMP |
| 5 | -36.400 | AGG | COMP | 15.100 | CEMENT | TEN |
| 6 | -29.180 | AGG | COMP | 16.000 | CEMENT | TEN |
| 7 | 9.410 | INTERFACE | TEN | -12.300 | INTERFACE | COMP |
| 8 | 20.60 | CEMENT | TEN | 5.100 | AGG | TEN |
| 9 | -8.910 | AGG | COMP | 6.800 | INTERFACE | TEN |
| 10 | 9.100 | CEMENT | TEN | 22.900 | CEMENT | TEN |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | 41.000 | INTERFACE | TEN | 21.400 | CEMENT | TEN |
| 12 | -51.080 | AGG | COMP | -3.900 | AGG | COMP |
| 13 | 22.900 | CEMENT | TEN | 7.200 | INTERFACE | TEN |
| 14 | -24.600 | AGG | COMP | 12.110 | CEMENT | TEN |
| 15 | 19.550 | INTERFACE | TEN | 13.250 | CEMENT | TEN |
| 16 | -9.900 | AGG | COMP | -7.350 | AGG | COMP |
| 17 | 34.18 | INTERFACE | TEN | 7.900 | CEMENT | TEN |
| 18 | 30.600 | CEMENT | TEN | 3.310 | INTERFACE | TEN |
| 19 | 21.900 | INTERFACE | TEN | -9.700 | AGG | COM |
| 20 | -23.400 | AGG | COMP | 7.100 | CEMENT | TEN |
| 21 | -31.890 | AGG | COMP | 18.000 | CEMENT | TEN |
| 22 | 23.970 | CEMENT | TEN | -15.310 | AGG | COM |
| 23 | 24.200 | INTERFACE | TEN | 14.000 | INTERFACE | TEN |
| 24 | -10.390 | AGG | COMP | 11.010 | CEMENT | TEN |
| 25 | -12.950 | AGG | COMP | -16.950 | AGG | COMP |
| 26 | -17.880 | AGG | COMP | -9.810 | AGG | COMP |
| 27 | 39.100 | INTERFACE | TEN | -9.310 | AGG | COMP |
| 28 | -15.780 | AGG | COMP | 1.020 | INTERFACE | TEN |
| 29 | 45.980 | CEMENT | TEN | -11.900 | AGG | COMP |
| 30 | 37.050 | CEMENT | TEN | 2.010 | INTERFACE | TEN |
| 31 | 56.700 | INTERFACE | TEN | -23.000 | AGG | COMP |
| 32 | -63.900 | AGG | COMP | 61.000 | CEMENT | TEN |
| 33 | 17.050 | INTERFACE | TEN | -28.400 | AGG | COMP |
| 34 | -3.700 | AGG | COM | 20.100 | CEMENT | TEN |
| 35 | 100.800 | INTERFACE | TEN | 4.900 | CEMENT | TEN |
| 36 | -64.600 | AGG | COMP | 7.200 | CEMENT | TEN |
| 37 | 20.100 | CEMENT | TEN | 31.200 | CEMENT | TEN |
| 38 | 23.2100 | INTERFACE | TEN | 40.110 | CEMENT | TEN |
| 39 | 72.990 | CEMENT | TEN | 31.120 | CEMENT | TEN |
| 40 | -91.670 | AGG | COMP | -60.010 | AGG | COMP |

**Table 6: Contour of normal stress (S11) at the transverse axisof concrete specimen and modeled as a single-phase materia**l

| tress location | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|
| 1 | 0.040 | CEMENT | TEN |
| 2 | 0.119 | CEMENT | TEN |
| 3 | 0.410 | CEMENT | TEN |
| 4 | 0.850 | CEMENT | TEN |
| 5 | 1.220 | CEMENT | TEN |
| 6 | 1.520 | CEMENT | TEN |
| 7 | 1.910 | CEMENT | TEN |
| 8 | 2.150 | CEMENT | TEN |
| 9 | 2.660 | CEMENT | TEN |
| 10 | 2.840 | CEMENT | TEN |
| 11 | 2.710 | CEMENT | TEN |
| 12 | 2.630 | CEMENT | TEN |
| 13 | 2.390 | CEMENT | TEN |
| 14 | 1.900 | CEMENT | TEN |
| 15 | 1.520 | CEMENT | TEN |
| 16 | 1.220 | CEMENT | TEN |
| 17 | 0.720 | CEMENT | TEN |
| 18 | 0.370 | CEMENT | TEN |
| 19 | 0.119 | CEMENT | TEN |
| 20 | 0.022 | CEMENT | TEN |

**Table 7: Normal stress (S11) at the transverse axis of concrete containedgraveland modeled asa double-phase material**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 9.180 | CEMENT | TEN | 4.900 | CEMENT | TEN |
| 2 | 2.800 | INTERFACE | TEN | 10.300 | CEMENT | TEN |
| 3 | -11.700 | AGG | COMP | 7.900 | CEMENT | TEN |
| 4 | 3.930 | INTERFACE | TEN | -9.100 | AGG | COMP |
| 5 | -23.110 | AGG | COM | 5.980 | INTERFACE | TEN |
| 6 | 40.100 | CEMENT | TEN | -6.200 | AGG | COMP |
| 7 | 49.200 | CEMENT | TEN | -20.100 | AGG | COMP |
| 8 | -18.250 | AGG | COMP | -7.900 | AGG | COMP |
| 9 | -28.400 | AGG | COMP | 11.350 | INTERFACE | TEN |
| 10 | 21.130 | CEMENT | TEN | 12.400 | CEMENT | TEN |
| 11 | 17.900 | CEMENT | TEN | 6.750 | CEMENT | TEN |
| 12 | 23.930 | INTERFACE | TEN | 7.100 | INTERFACE | TEN |
| 13 | 38.700 | CEMENT | TEN | -8.090 | AGG | COMP |
| 14 | -50.300 | AGG | COMP | -11.800 | AGG | COMP |
| 15 | 5.930 | CEMENT | TEN | 17.900 | INTERFACE | TEN |
| 16 | -16.900 | AGG | COMP | 24.900 | CEMENT | TEN |
| 17 | -20.110 | AGG | COMP | -6.950 | AGG | COMP |
| 18 | 15.900 | INTERFACE | TEN | 16.750 | INTERFACE | TEN |
| 19 | 22.130 | CEMENT | TEN | 13.390 | CEMENT | TEN |
| 20 | -14.010 | AGG | COMP | 12.610 | CEMENT | TEN |
| 21 | 6.350 | CEMENT | TEN | 3.020 | INTERFACE | TEN |
| 22 | 3.600 | CEMENT | TEN | 3.600 | CEMENT | TEN |
| 23 | 38.000 | CEMENT | TEN | 38.000 | CEMENT | TEN |
| 24 | 0.900 | CEMENT | TEN | 0.900 | CEMENT | TEN |

**Table8: Normal stress (S11) at the transverse axis of concrete contained dolomiteand modeled as a double-phase material**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 11.800 | CEMENT | TEN | 6.040 | CEMENT | TEN |
| 2 | 3.900 | INTERFACE | TEN | 12.000 | CEMENT | TEN |
| 3 | 13.700 | INTERFACE | TEN | 9.700 | CEMENT | TEN |
| 4 | 5.160 | CEMENT | TEN | 10.700 | CEMENT | TEN |
| 5 | -26.500 | AGG | COMP | 7.160 | INTERFACE | TEN |
| 6 | 66.300 | CEMENT | TEN | -7.700 | AGG | COMP |
| 7 | 68.600 | CEMENT | TEN | -23.800 | AGG | COMP |
| 8 | 21.500 | CEMENT | TEN | 9.200 | INTERFACE | TEN |
| 9 | 31.400 | INTERFACE | TEN | 13.580 | INTERFACE | TEN |
| 10 | -18.750 | AGG | COMP | -13.100 | AGG | COMP |
| 11 | 20.680 | CEMENT | TEN | -9.800 | AGG | COMP |
| 12 | -15.800 | AGG | COMP | 8.900 | INTERFACE | TEN |
| 13 | 44.200 | INTERFACE | TEN | 8.140 | INTERFACE | TEN |
| 14 | 39.600 | INTERFACE | TEN | 13.900 | CEMENT | TEN |
| 15 | -4.100 | AGG | COMP | -20.700 | AGG | COMP |
| 16 | 18.7000 | CEMENT | TEN | -28.700 | AGG | COMP |
| 17 | 22.200 | CEMENT | TEN | 8.300 | INTERFACE | TEN |
| 18 | -17.060 | AGG | COMP | 22.300 | CEMENT | TEN |
| 19 | -24.360 | AGG | COMP | -16.700 | AGG | COMP |
| 20 | 15.257 | CEMENT | TEN | -15.800 | AGG | COMP |

**Table 9: Normal Stress (S11) at the vertical and horizontal axes of concrete specimen and modeled as a single-phase material**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -794.040 | CEMENT | COMP | 0.095 | CEMENT | COMP |
| 2 | -28.140 | CEMENT | COMP | 0.269 | CEMENT | COMP |
| 3 | 14.660 | CEMENT | TEN | 0.564 | CEMENT | TEN |
| 4 | 17.290 | CEMENT | TEN | 1.590 | CEMENT | TEN |
| 5 | 17.550 | CEMENT | TEN | 2.340 | CEMENT | TEN |
| 6 | 17.990 | CEMENT | TEN | 4.350 | CEMENT | TEN |
| 7 | 18.350 | CEMENT | TEN | 7.012 | CEMENT | TEN |
| 8 | 18.760 | CEMENT | TEN | 10.130 | CEMENT | TEN |
| 9 | 18.940 | CEMENT | TEN | 13.370 | CEMENT | TEN |
| 10 | 18.960 | CEMENT | TEN | 17.400 | CEMENT | TEN |
| 11 | 18.990 | CEMENT | TEN | 18.990 | CEMENT | TEN |
| 12 | 19.010 | CEMENT | TEN | 18.270 | CEMENT | TEN |
| 13 | 18.970 | CEMENT | TEN | 16.260 | CEMENT | TEN |
| 14 | 18.910 | CEMENT | TEN | 13.370 | CEMENT | TEN |
| 15 | 18.810 | CEMENT | TEN | 10.760 | CEMENT | TEN |
| 16 | 18.610 | CEMENT | TEN | 8.500 | CEMENT | TEN |
| 17 | 18.200 | CEMENT | TEN | 5.600 | CEMENT | TEN |
| 18 | 17.780 | CEMENT | TEN | 3.260 | CEMENT | TEN |
| 19 | 16.150 | CEMENT | TEN | 1.000 | CEMENT | TEN |
| 20 | -31.460 | CEMENT | COMP | 0.564 | CEMENT | COMP |
| 21 | -9.170 | CEMENT | COMP | 0.269 | CEMENT | COMP |
| 22 | -795.570 | CEMENT | COMP | 0.095 | CEMENT | COMP |

**Table 10: Normal Stress (S11) at the vertical axis of concrete contained gravel and modeled as a double-phase material - top section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -923.230 | CEMENT | COMP | -889.930 | CEMENT | COMP |
| 2 | -28.1100 | CEMENT | COMP | -20.030 | INTERFACE | COMP |
| 3 | 3.500 | AGG | TEN | 17.850 | AGG | TEN |
| 4 | 8.120 | CEMENT | TEN | 14.610 | AGG | TEN |
| 5 | 33.410 | AGG | TEN | 31.150 | CEMENT | TEN |
| 6 | 17.850 | INTERFACE | TEN | 15.870 | INTERFACE | TEN |
| 7 | 11.130 | CEMENT | TEN | 10.150 | AGG | TEN |
| 8 | 17.150 | AGG | TEN | 20.800 | CEMENT | TEN |
| 9 | 22.960 | INTERFACE | TEN | 21.110 | INTERFACE | TEN |
| 10 | 32.560 | AGG | TEN | 28.030 | AGG | TEN |
| 11 | 25.750 | CEMENT | TEN | 23.850 | CEMENT | TEN |
| 12 | 21.410 | INTERFACE | TEN | 20.150 | INTERFACE | TEN |
| 13 | 29.390 | INTERFACE | TEN | 19.970 | AGG | TEN |
| 14 | 26.530 | AGG | TEN | 25.780 | AGG | TEN |
| 15 | 19.610 | INTERFACE | TEN | 24.110 | CEMENT | TEN |
| 16 | 47.110 | AGG | TEN | 45.320 | INTERFACE | TEN |
| 17 | 16.840 | AGG | TEN | 20.200 | AGG | TEN |
| 18 | 1.120 | CEMENT | TEN | 11.220 | CEMENT | TEN |
| 19 | 6.800 | CEMENT | TEN | 8.150 | CEMENT | TEN |
| 20 | -32.890 | CEMENT | COMP | -36.000 | INTERFACE | COMP |
| 21 | -141.160 | CEMENT | COMP | -140.1100 | AGG | COMP |
| 22 | -1099.130 | CEMENT | COMP | -1100.120 | CEMENT | COMP |

**Table 11: Normal Stress (S11) at the horizontal axis of concrete contained gravel and modeled asa double-phase material- top section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 0.079 | CEMENT | TEN | 0.051 | CEMENT | TEN |
| 2 | 0.350 | CEMENT | TEN | 0.280 | CEMENT | TEN |
| 3 | 0.580 | CEMENT | TEN | 0.420 | INTERFACE | TEN |
| 4 | 1.090 | INTERFACE | TEN | 0.980 | AGG | TEN |
| 5 | 3.340 | AGG | TEN | 2.860 | AGG | TEN |
| 6 | 5.370 | AGG | TEN | 4.910 | CEMENT | TEN |
| 7 | 10.220 | CEMENT | TEN | 9.120 | INTERFACE | TEN |
| 8 | 13.010 | INTERFACE | TEN | 12.310 | AGG | TEN |
| 9 | 21.670 | INTERFACE | TEN | 21.000 | CEMENT | TEN |
| 10 | 30.330 | CEMENT | TEN | 29.650 | AGG | TEN |
| 11 | 28.790 | CEMENT | TEN | 23.850 | CEMENT | TEN |
| 12 | 29.210 | CEMENT | TEN | 26.450 | INTERFACE | TEN |
| 13 | 26.110 | AGG | TEN | 21.870 | AGG | TEN |
| 14 | 14.090 | INTERFACE | TEN | 14.250 | AGG | TEN |
| 15 | 15.890 | AGG | TEN | 13.250 | CEMENT | TEN |
| 16 | 9.440 | INTERFACE | TEN | 10.110 | INTERFACE | TEN |
| 17 | 10.100 | CEMENT | TEN | 8.220 | AGG | TEN |
| 18 | 2.890 | CEMENT | TEN | 1.060 | INTERFACE | TEN |
| 19 | 4.960 | INTERFACE | TEN | 2.630 | CEMENT | TEN |
| 20 | 0.830 | AGG | TEN | 4.090 | CEMENT | TEN |
| 21 | 0.240 | AGG | TEN | 0.610 | CEMENT | TEN |
| 22 | 0.099 | CEMENT | TEN | 0.041 | CEMENT | TEN |

**Table 12:Normal stress (S11) at the vertical axis of concrete contained dolomite and modeled as a double-phase material- top section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -818.000 | CEMENT | COMP | -802.5 | CEMENT | COMP |
| 2 | -32.200 | CEMENT | COMP | -15.45 | CEMENT | COMP |
| 3 | 18.100 | CEMENT | TEN | 19.8 | INTERFACE | TEN |
| 4 | 27.120 | INTERFACE | TEN | 15.6 | AGGREGATE | TEN |
| 5 | 19.260 | CEMENT | TEN | 9.06 | INTERFACE | TEN |
| 6 | 16.970 | INTERFACE | TEN | 16.09 | AGGREGATE | TEN |
| 7 | 20.130 | AGGREGATE | TEN | 13.11 | AGGREGATE | TEN |
| 8 | 32.900 | AGGREGATE | TEN | 13.65 | INTERFACE | TEN |
| 9 | 19.550 | CEMENT | TEN | 18.15 | CEMENT | TEN |
| 10 | 19.100 | CEMENT | TEN | 16.4 | INTERFACE | TEN |
| 11 | 19.690 | AGGREGATE | TEN | 17.45 | CEMENT | TEN |
| 12 | 24.600 | AGGREGATE | TEN | 19.4 | CEMENT | TEN |
| 13 | 23.980 | AGGREGATE | TEN | 21.2 | AGGREGATE | TEN |
| 14 | 20.600 | INTERFACE | TEN | 23.25 | INTERFACE | TEN |
| 15 | 19.590 | INTERFACE | TEN | 18.1 | CEMENT | TEN |
| 16 | 20.330 | AGGREGATE | TEN | 40.6 | CEMENT | TEN |
| 17 | 15.040 | CEMENT | TEN | 18.1 | INTERFACE | TEN |
| 18 | 2.300 | AGGREGATE | TEN | 10.1 | CEMENT | TEN |
| 19 | 1.700 | INTERFACE | TEN | 6.71 | INTERFACE | TEN |
| 20 | -25.250 | CEMENT | COMP | -31 | CEMENT | COMP |
| 21 | -122.070 | CEMENT | COMP | -130.2 | CEMENT | COMP |
| 22 | -787.860 | CEMENT | COMP | -974.1 | CEMENT | COMP |

**Table13: Normal stress (S11) at the horizontal axis of concrete contained dolomite and modeled as a double-phase material- top section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 0.032 | CEMENT | TEN | 0.040 | CEMENT | TEN |
| 2 | 0.031 | INTERFACE | TEN | 0.210 | CEMENT | TEN |
| 3 | 0.048 | CEMENT | TEN | 0.310 | CEMENT | TEN |
| 4 | 0.910 | AGGREGATE | TEN | 0.950 | INTERFACE | TEN |
| 5 | 3.100 | AGGREGATE | TEN | 2.400 | AGGREGATE | TEN |
| 6 | 4.290 | CEMENT | TEN | 3.850 | AGGREGATE | TEN |
| 7 | 9.140 | INTERFACE | TEN | 8.150 | CEMENT | TEN |
| 8 | 12.750 | CEMENT | TEN | 11.400 | INTERFACE | TEN |
| 9 | 19.100 | AGGREGATE | TEN | 20.300 | AGGREGATE | TEN |
| 10 | 23.440 | AGGREGATE | TEN | 27.750 | AGGREGATE | TEN |
| 11 | 21.010 | CEMENT | TEN | 19.450 | CEMENT | TEN |
| 12 | 28.720 | CEMENT | TEN | 24.650 | INTERFACE | TEN |
| 13 | 22.450 | CEMENT | TEN | 18.130 | AGGREGATE | TEN |
| 14 | 14.600 | INTERFACE | TEN | 12.400 | AGGREGATE | TEN |
| 15 | 11.870 | AGGREGATE | TEN | 11.400 | CEMENT | TEN |
| 16 | 4.430 | CEMENT | TEN | 9.070 | INTERFACE | TEN |
| 17 | 2.600 | AGGREGATE | TEN | 5.430 | CEMENT | TEN |
| 18 | 1.000 | INTERFACE | TEN | 0.980 | AGGREGATE | TEN |
| 19 | 2.700 | AGGREGATE | TEN | 2.400 | AGGREGATE | TEN |
| 20 | 0.700 | INTERFACE | TEN | 3.850 | CEMENT | TEN |
| 21 | 0.150 | CEMENT | TEN | 0.230 | CEMENT | TEN |
| 22 | 0.083 | CEMENT | TEN | 0.039 | CEMENT | TEN |

**Table 14: Normal stress (S11) at the vertical axis of concrete contained gravel and modeled as a double-phase material - mid section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -950.12 | CEMENT | COMP | -818.400 | CEMENT | COMP |
| 2 | -33.780 | CEMENT | COMP | -16.400 | INTERFACE | COMP |
| 3 | 23.600 | INTERFACE | TEN | 17.260 | CEMENT | TEN |
| 4 | 17.920 | AGG | TEN | 23.940 | AGG | TEN |
| 5 | 38.170 | AGG | TEN | 14.690 | INTERFACE | TEN |
| 6 | 18.650 | INTERFACE | TEN | 15.560 | AGG | TEN |
| 7 | 10.830 | INTERFACE | TEN | 18.730 | INTERFACE | TEN |
| 8 | 20.950 | CEMENT | TEN | 20.350 | CEMENT | TEN |
| 9 | 24.620 | AGG | TEN | 18.110 | INTERFACE | TEN |
| 10 | 34.950 | CEMENT | TEN | 10.330 | CEMENT | TEN |
| 11 | 28.790 | CEMENT | TEN | 20.440 | CEMENT | TEN |
| 12 | 27.830 | CEMENT | TEN | 25.750 | INTERFACE | TEN |
| 13 | 23.160 | INTERFACE | TEN | 23.350 | AGG | TEN |
| 14 | 29.170 | CEMENT | TEN | 22.710 | CEMENT | TEN |
| 15 | 24.980 | INTERFACE | TEN | 26.010 | INTERFACE | TEN |
| 16 | 47.370 | AGG | TEN | 37.650 | CEMENT | TEN |
| 17 | 20.720 | CEMENT | TEN | 19.600 | AGG | TEN |
| 18 | 1.600 | INTERFACE | TEN | 14.800 | CEMENT | TEN |
| 19 | 7.640 | CEMENT | TEN | 5.300 | INTERFACE | TEN |
| 20 | -36.900 | CEMENT | COMP | -32.000 | AGG | COMP |
| 21 | -145.950 | CEMENT | COMP | -120.290 | CEMENT | COMP |
| 22 | -1130.750 | CEMENT | COMP | -516.180 | CEMENT | COMP |

**Table 15: Normal stress (S11) at the horizontal axis of concrete contained gravel and modeled as a double-phase material - mid section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 0.098 | CEMENT | TEN | 0.049 | CEMENT | TEN |
| 2 | 0.310 | CEMENT | TEN | 0.015 | CEMENT | TEN |
| 3 | 0.500 | INTERFACE | TEN | 0.040 | INTERFACE | TEN |
| 4 | 0.950 | AGG | TEN | 0.900 | AGG | TEN |
| 5 | 2.950 | AGG | TEN | 2.300 | CEMENT | TEN |
| 6 | 5.090 | CEMENT | TEN | 3.950 | CEMENT | TEN |
| 7 | 8.810 | INTERFACE | TEN | 7.130 | INTERFACE | TEN |
| 8 | 11.990 | AGG | TEN | 12.300 | AGG | TEN |
| 9 | 19.800 | INTERFACE | TEN | 16.500 | CEMENT | TEN |
| 10 | 30.020 | CEMENT | TEN | 26.100 | CEMENT | TEN |
| 11 | 25.750 | CEMENT | TEN | 20.440 | CEMENT | TEN |
| 12 | 29.000 | CEMENT | TEN | 22.850 | CEMENT | TEN |
| 13 | 25.190 | INTERFACE | TEN | 18.370 | INTERFACE | TEN |
| 14 | 12.090 | AGG | TEN | 13.740 | AGG | TEN |
| 15 | 14.630 | AGG | TEN | 10.390 | AGG | TEN |
| 16 | 8.310 | INTERFACE | TEN | 7.950 | CEMENT | TEN |
| 17 | 10.300 | CEMENT | TEN | 0.809 | CEMENT | TEN |
| 18 | 1.950 | CEMENT | TEN | 0.915 | CEMENT | TEN |
| 19 | 4.110 | AGG | TEN | 3.040 | INTERFACE | TEN |
| 20 | 0.710 | INTERFACE | TEN | 0.325 | CEMENT | TEN |
| 21 | 0.160 | CEMENT | TEN | 0.140 | CEMENT | TEN |
| 22 | 0.088 | CEMENT | TEN | 0.018 | CEMENT | TEN |

**Table 16: Normal stress (S11) at the vertical axis of concrete contained dolomite and modeled as a double-phase material - mid section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | -904.310 | CEMENT | COMP | -711.600 | CEMENT | COMP |
| 2 | -29.800 | CEMENT | COMP | -13.280 | CEMENT | COMP |
| 3 | 19.350 | INTERFACE | TEN | 15.330 | CEMENT | TEN |
| 4 | 11.310 | CEMENT | TEN | 21.620 | INTERFACE | TEN |
| 5 | 29.320 | CEMENT | TEN | 12.600 | AGG | TEN |
| 6 | 16.150 | AGGREGATE | TEN | 14.380 | AGG | TEN |
| 7 | 8.900 | INTERFACE | TEN | 16.680 | INTERFACE | TEN |
| 8 | 18.000 | AGGREGATE | TEN | 20.240 | CEMENT | TEN |
| 9 | 21.270 | INTERFACE | TEN | 17.100 | CEMENT | TEN |
| 10 | 32.250 | CEMENT | TEN | 13.650 | INTERFACE | TEN |
| 11 | 21.010 | CEMENT | TEN | 16.150 | CEMENT | TEN |
| 12 | 23.440 | AGGREGATE | TEN | 22.980 | INTERFACE | TEN |
| 13 | 18.030 | CEMENT | TEN | 21.380 | AGG | TEN |
| 14 | 22.650 | CEMENT | TEN | 20.110 | INTERFACE | TEN |
| 15 | 21.900 | INTERFACE | TEN | 25.330 | INTERFACE | TEN |
| 16 | 46.950 | CEMENT | TEN | 35.440 | CEMENT | TEN |
| 17 | 15.140 | CEMENT | TEN | 16.400 | AGG | TEN |
| 18 | 1.700 | AGGREGATE | TEN | 12.370 | CEMENT | TEN |
| 19 | 4.600 | AGGREGATE | TEN | 4.740 | INTERFACE | TEN |
| 20 | -36.120 | CEMENT | COMP | -29.000 | AGG | COMP |
| 21 | -125.580 | CEMENT | COMP | -112.970 | CEMENT | COMP |
| 22 | -1074.380 | CEMENT | COMP | -601.500 | CEMENT | COMP |

**Table 17: Normal stress (S11) at the horizontal axis of concrete contained dolomite and modeled as a double-phase material - mid section**

| Stress location | Stress (kg/cm$^2$) | Location | Type | Stress (kg/cm$^2$) | Location | Type |
|---|---|---|---|---|---|---|
| | Manual compaction | | | Mechanical compaction | | |
| 1 | 0.018 | CEMENT | TEN | 0.040 | CEMENT | TEN |
| 2 | 0.250 | CEMENT | TEN | 0.190 | CEMENT | TEN |
| 3 | 0.430 | INTERFACE | TEN | 0.490 | INTERFACE | TEN |
| 4 | 1.020 | AGGREGATE | TEN | 0.830 | AGGREGATE | TEN |
| 5 | 2.160 | CEMENT | TEN | 2.100 | CEMENT | TEN |
| 6 | 6.190 | CEMENT | TEN | 5.060 | CEMENT | TEN |
| 7 | 9.660 | CEMENT | TEN | 6.750 | INTERFACE | TEN |
| 8 | 13.400 | INTERFACE | TEN | 11.100 | INTERFACE | TEN |
| 9 | 18.570 | INTERFACE | TEN | 15.400 | CEMENT | TEN |
| 10 | 19.780 | INTERFACE | TEN | 18.330 | CEMENT | TEN |
| 11 | 21.600 | AGGREGATE | TEN | 20.215 | CEMENT | TEN |
| 12 | 24.110 | INTERFACE | TEN | 21.750 | AGGREGATE | TEN |
| 13 | 17.570 | CEMENT | TEN | 17.110 | INTERFACE | TEN |
| 14 | 15.010 | CEMENT | TEN | 13.970 | AGGREGATE | TEN |
| 15 | 12.910 | INTERFACE | TEN | 11.970 | INTERFACE | TEN |
| 16 | 10.240 | AGGREGATE | TEN | 8.450 | CEMENT | TEN |
| 17 | 6.750 | CEMENT | TEN | 6.100 | CEMENT | TEN |
| 18 | 5.210 | INTERFACE | TEN | 4.816 | INTERFACE | TEN |
| 19 | 4.200 | AGGREGATE | TEN | 2.900 | INTERFACE | TEN |
| 20 | 1.090 | AGGREGATE | TEN | 0.650 | CEMENT | TEN |
| 21 | 0.680 | CEMENT | TEN | 0.310 | CEMENT | TEN |
| 22 | 0.015 | CEMENT | TEN | 0.010 | CEMENT | TEN |

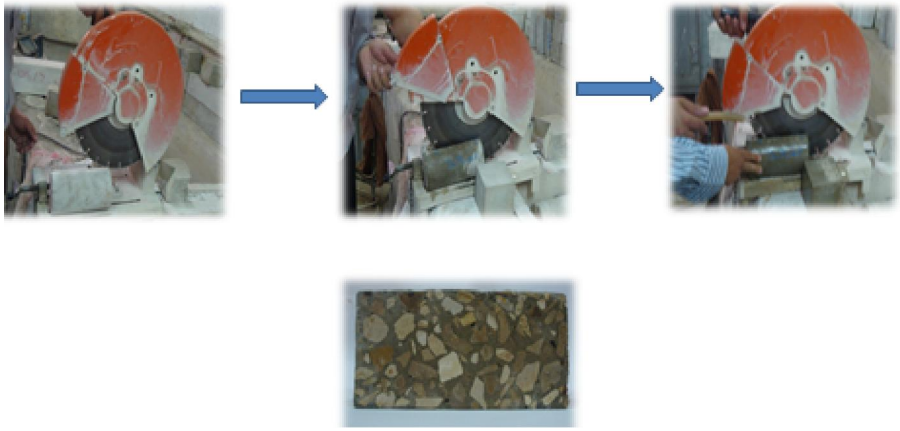


**Photo (1): Preparing the longitudinal sections**

**Photo (2): Preparing the horizontal sections**

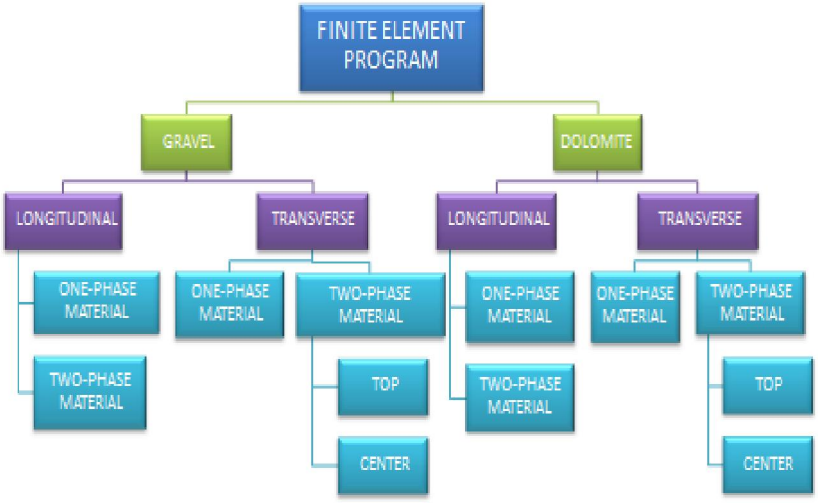



**Photo (3): The finite element program**

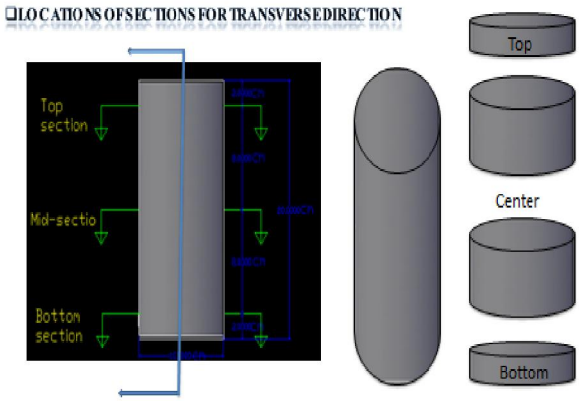



**Figure (1): Longitudinal and horizontal circular sections photographed by digital camera**

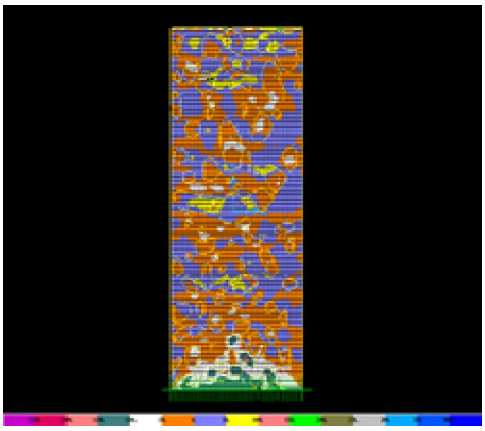


Figure (3): Contour of normal stress S11 of concrete specimen contained gravel and modeled as a double-phase material **(Manual compaction)**

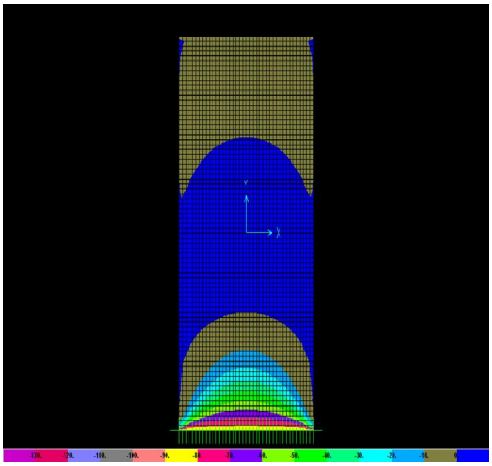


**Figure (2): Contour of normal stress S11 of concrete specimen modeled as a single phase-material**

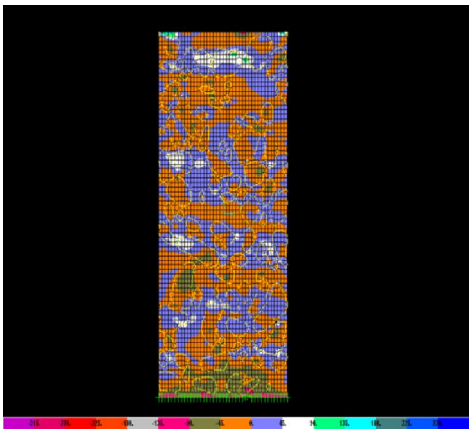


**Figure (4): Contour of normal stress S11 of concrete specimen contained gravel and modeled as a double-phase material (Mechanical compaction)**

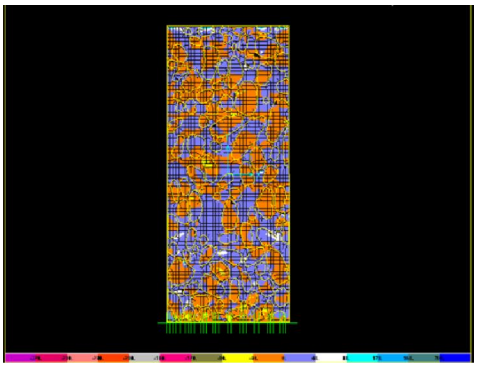


**Figure (5): Contour of normal stress S11 of concrete specimen contained dolomite and modeled as a double-phase material(Manual compaction)**

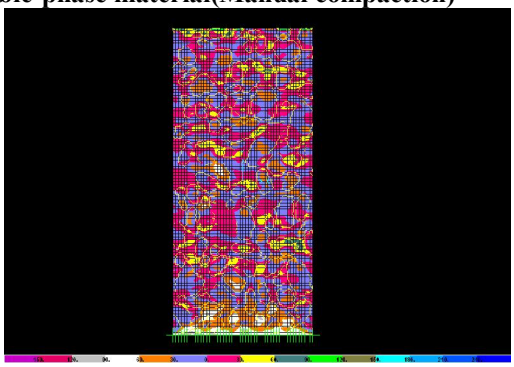


**Figure (6): Contour of normal stress S11 of concrete specimen contained dolomite and modeled as a double-phase material (Mechanical compaction)**

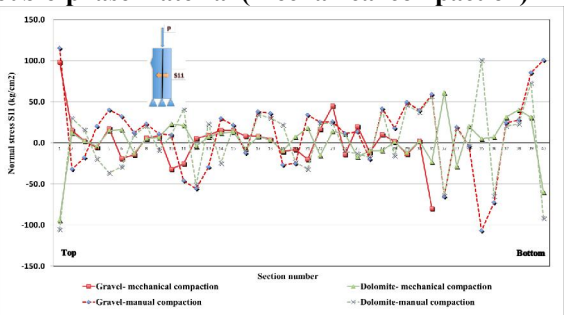



**Figure (7): Normal stress S11 at the longitudinal axis of concrete contained gravel and dolomite (Manual and mechanical compaction)**

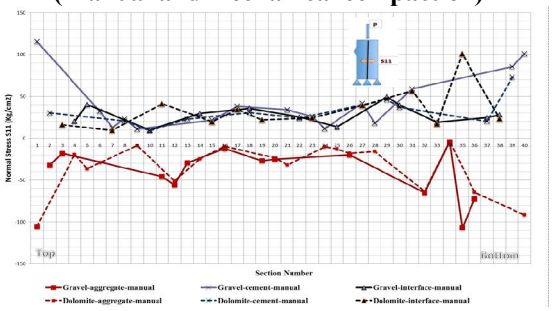



**Figure (8): Normal Stress S11 at the different Phases at the longitudinal axis of concrete contained gravel and dolomite (Manual and mechanical compaction)**

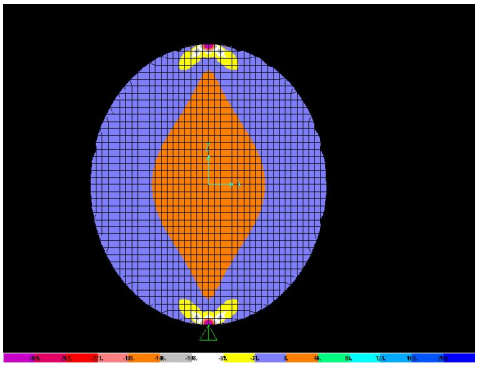


**Figure (9): Contour of normal stress (S11) of concrete specimen modeled as a single-phase material**

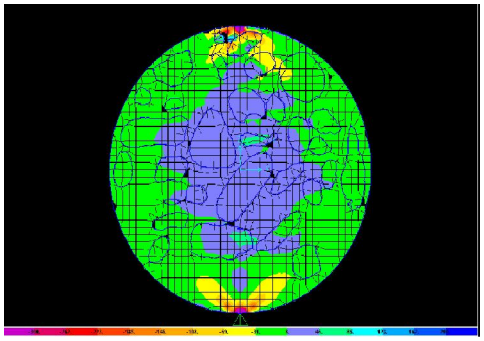


**Figure (10): Normal stress [S11] at top section of concrete containedgravel and compacted manually**

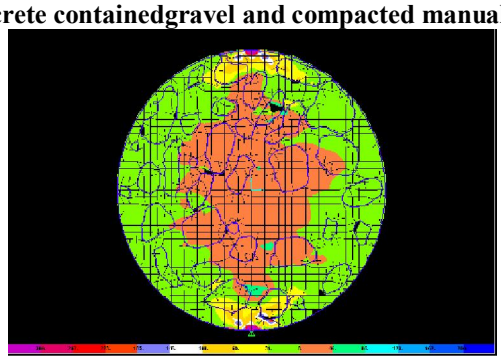


**Figure (11): Normal Stress [S11] at topsection of concrete contained gravel and compacted mechanically**

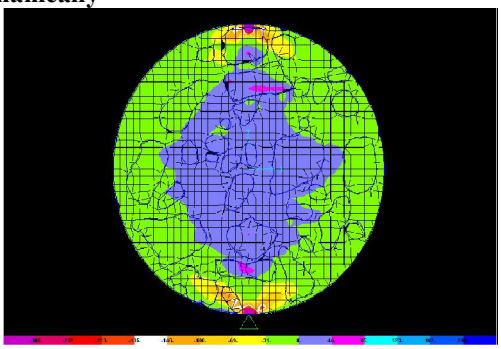


**Figure (12): Normal stress [S11] at top section of concrete contained dolomite and compacted manually**

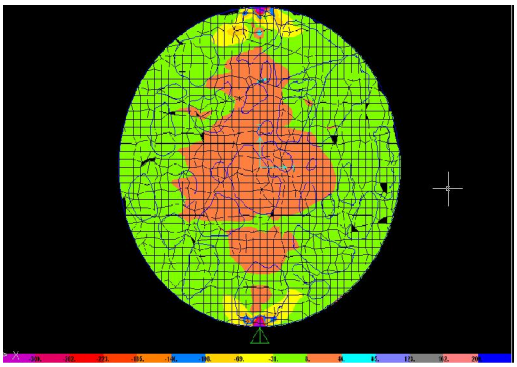


**Figure (13): Normal stress [S11] at top section of concrete contained dolomite and compacted mechanically**

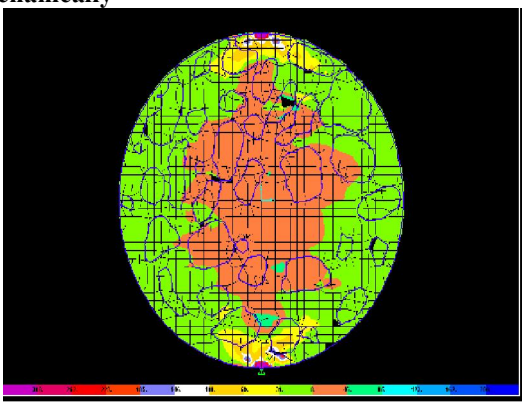


**Figure (14): Normal stress [S11] at center section of concrete contained gravel and compacted manually**

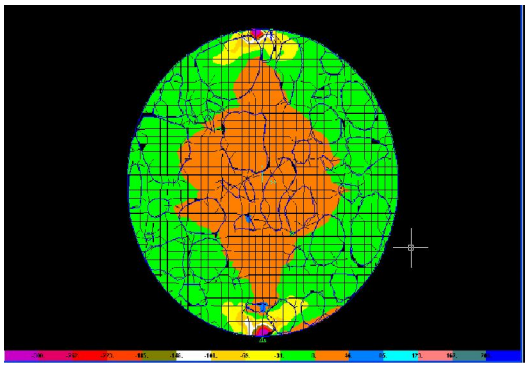


**Figure (15): Normal stress [S11] atcentersection of concrete contained gravel and compacted mechanically**

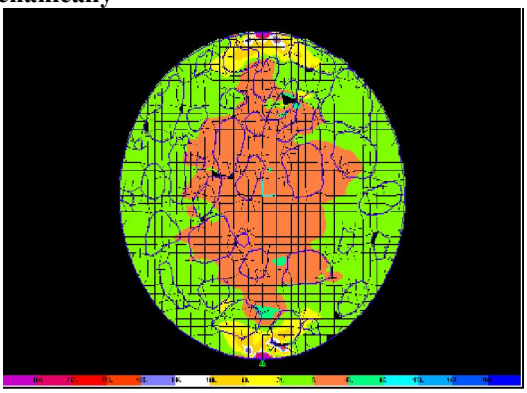
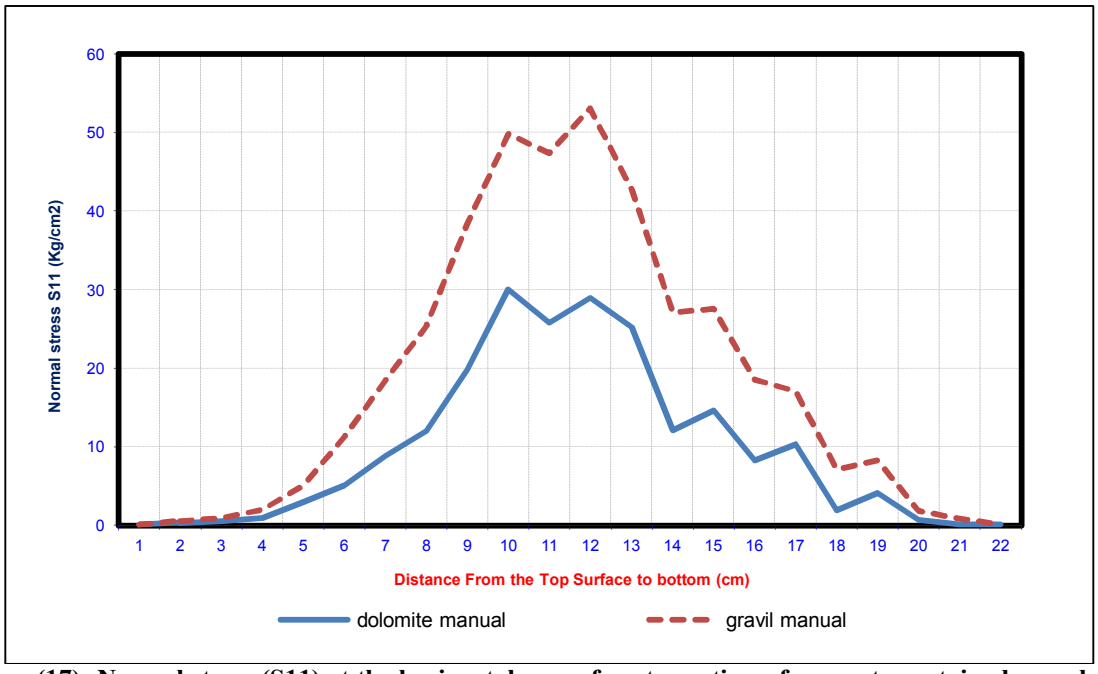


**Figure (16): Normal Stress [S11] at center section of concrete contained dolomite and compacted manually**




**Figure(17): Normal stress (S11) at the horizontal axes of centersectionsof concrete contained gravel and dolomite aggregate - (Manual compaction)**

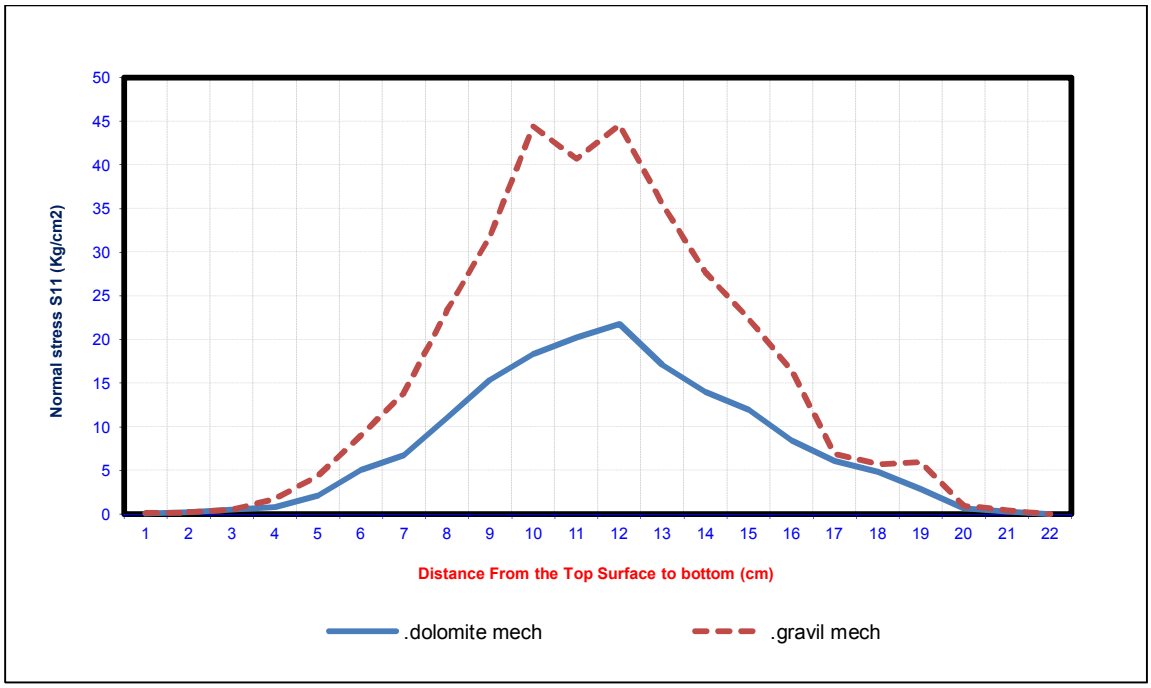



**Figure (18): Normal stress (S11) at the horizontal axes of center sections of concrete contained gravel and dolomite aggregate - (Mechanical compaction)**

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