Simulation of Lateral Earth Structure Resting on Gypseous Soil

Lecturer. Dr. Safa Hussain Abid Awn
College of Engineering/Civil Eng. Department Diyala University
Safa_alshamary@yahoo.com

Abstract:

*This study includes the behavior of lateral earth structure constructed on gypseous soil, wherein some cases we are forced to construct such heavy structure over such collapsible soil which may cause severe damages for structures constructed on. To recognize such special case, locally manufactured laboratory model was designed for this study. The model includes, a thick and stiffened in side, rectangular plastic container (800*500*400mm) . The soil used was natural gypseous soil with 5%gypsum content as a reference. an additional gypsum percentages were mixed with the 5% gypseous soil reaches (25%, 40%, and 60%).The gypseous soil was compacted to 18kN/m^3 density, placed at lower portion of container. A gravity precast concrete structure was prepared and placed over the collapsible soil. Highly permeable granular soil was placed beside the lateral gravity structure. Dial gauges were fixed at top and beside the lateral concrete structure to investigate the vertical and horizontal deflection of such structures at dry and upon wetting by water from special device manufactured locally, to simulate the rainfall of water from top of model, as in nature.*

The vertical and horizontal movements of the concrete wall are totally random, that is due to the uneven settlement of wall resting on gypseous soil specially after 24 hour of continuous flooding of water because of fluctuation of water between soil particles and high dissolution of gypsum may have happened after this period due to leaching process and cavity formation below the heavy concrete wall. And so the dangerous from leaching is more than that of soaking of such case.

The study includes also the possibility to improve the behavior such structures, by mixing gypseous soil, with 3% cement. The horizontal and vertical movements reduces to more than 25% and 90%, respectively.

Key Word: Lateral earth, Gypseous soil, Cement Improvement.

تمثيل منشأ لجدار ساند مشيد على تربه جبسيه

م.د صفاء حسين عبد عون
جامعة ديالى / كلية الهندسة / قسم الهندسة المدنية

الخلاصة :

تتطرق هذه الدراسة لتصرف الجدران المعرضة لضغط تراب جانبي والمقامة على تربة جبسيه. حيث إننا نضطر في بعض الأحيان لتشييد مثل هذه المنشات الثقيلة فوق هذا النوع من الترب الذي يشكل خطراً على المنشات المقامة عليها. وللتعرف على هذه الحالة الخاصة، تم استخدام موديل مختبري مصنع محلياً ، مكون من حاويه بلاستيكيه سميكة بإبعاد 40*50*80سم و ذات حزوز عموديه لاسناد و تقوية جوانب الحاوية إثناء الفحص. تم استخدام تربه جبسيه طبيعيه بنسب جبس مختلفة (5 %، 25 %، 40 %، 60 %) تم رصها بكثافة رص 18 كيلونوتن/متر مكعب وضعت اسفل منشأ إسمنتي مسبق الصب تم تحضيره في المختبر. تم وضع تراب الردم المكون من تربه رمليه عالية النفاذية، بجانب المنشأ الكونكريتي. تم وضع مقاييس نابضيه من الاعلى وعلى جانب المنشا الترابي، لدراسة تصرفه اثناء ترطيب تراب الردم بالماء من مصدر شبيه لتعرض المنشأ لمياه الامطار باستعمال مرشه خاصة تم تصميمها وتصنيعها خصيصا لهذه الدراسة.

اظهرت النتائج المستخلصة من الموديل المختبري، ان كانت بشكل عشوائي تماما، وهو نتيجة الهبوط التبايني للجدار المنشأ على التربة الجبسية، وخاصة بعد 24 ساعة من عملية الغسل المستمرة . بسبب تغلغل المياه بين جزيئات التربة، وحدوث انحلال عالي للجبس قد يكون حدث بعد هذه الفترة بسبب عملية الترشيح المتسارع وتشكيل تجويف تحت الجدار الخرساني . وبالتالي فإن الخطورة من من عملية الغسل للتربه تحت المنشأ الكونكريتي هو أكثر من غمرها او ترطيبها.

وتشمل الدراسة أيضا إمكانية تحسين سلوك مثل هذه المنشآت، من خلال خلط التربة الجبسية، مع 3٪ الاسمنت.حيث تم تخفيض الحركات الأفقية والرأسية لاكثر من 25٪ و 90٪ على التوالي.

مفتاح الكلمات: الضغط الجانبي، الترب الجبسيه، المعالجة بالاسمنت.

1. Introduction:

A gravity structures is typically used to form the permanent wall of an excavation wherever space requirement make it impractical or even impossible to simply slope the sides of the excavation[1,2]. As a matter of fact such situations arise when a road for example or storage area is needed immediately adjacent to an excavation. In order to construct a wall, a temporary slope is formed at the edge of the excavation, wall is built, and then backfill is dumped into the space between wall and the temporary slope . It is worth to mention that in earlier days masonry wall were often used[3] .Today, most walls are of concrete although special forms of construction are used[4]. There are other many situation in which many movements of retaining structures must be given serious consideration where consideration of stability only is inadequate for a proper design.

Retaining structure has traditionally been used on the specification of a factor of safety against overturning (the ratio of the resisting moment to the driving moment). and the factor of safty against sliding (friction resistant mobilized at the wall base with soil, to the active force from soil beside the wall).This factor of safety is given a value high enough to allow for all uncertainties in the analytical method and in the value of soil parameters[5]. However, it must be recognized that relatively large safety factor are required for the mobilization of available active force and that a structure could be deemed to have failed due to excessive deformation before reaching a condition of collapse.

There are many improvement techniques to reduce the collapse behavior of gypseous soils. Some are physical, like reinforcement, compaction. The others are chemical, by adding percent of lime, bituminous, silica, cement and others[8]. Cement is one of the most effective additive material for stabilization and improvement of the engineering properties of gypseous soil, so it works as a bond agent between soil particles, and will reduce the collapsibility and permeability of such soil, and mixing gypseous soil with about 4% cement reduce 80% of collapsibility[13].

Krishnaiah and Suryanarayana (2008) showed that the addition of 3% of cement, gives a considerable strength for stabilization when mixing with it. Above and below this range, the strength will be less. And shows that, the silica content in cement, may contribute with the strength and give fewer results[14]. The decision was made to use 3% percent of cement mix with gypseoues soils.

2. Experimental work:

This section illustrates the description of setup used and soil used in this study. It is intended, as well to give a perspective picture of the problem since similar problems do exist in Iraq such as the national dam in Mosul which is a huge dam resting on collapsible rocks, and Al-Nekhaila region in south of Jeddah in Saudi Arabia [6]. Since then continuous grouting in soil under dam is going on to stop or at least reduce the settlement of dam with time[7]. The testing program flow chart is shown in **Figure (1).**

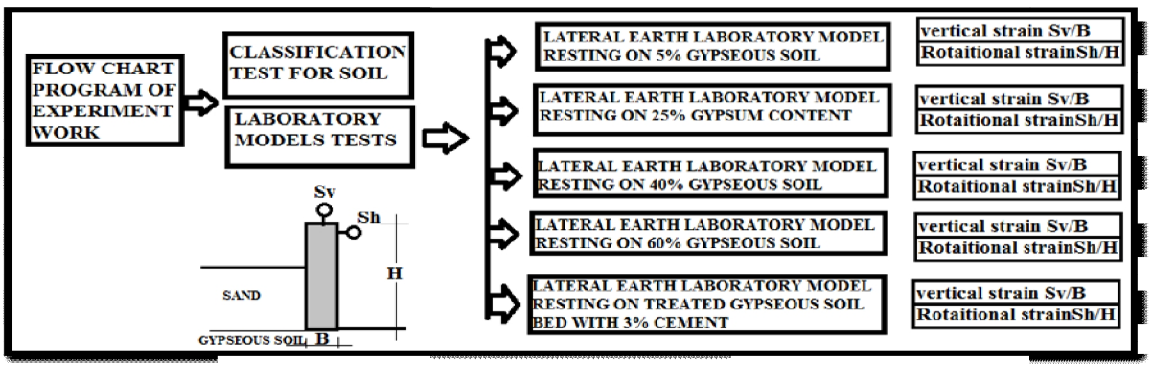
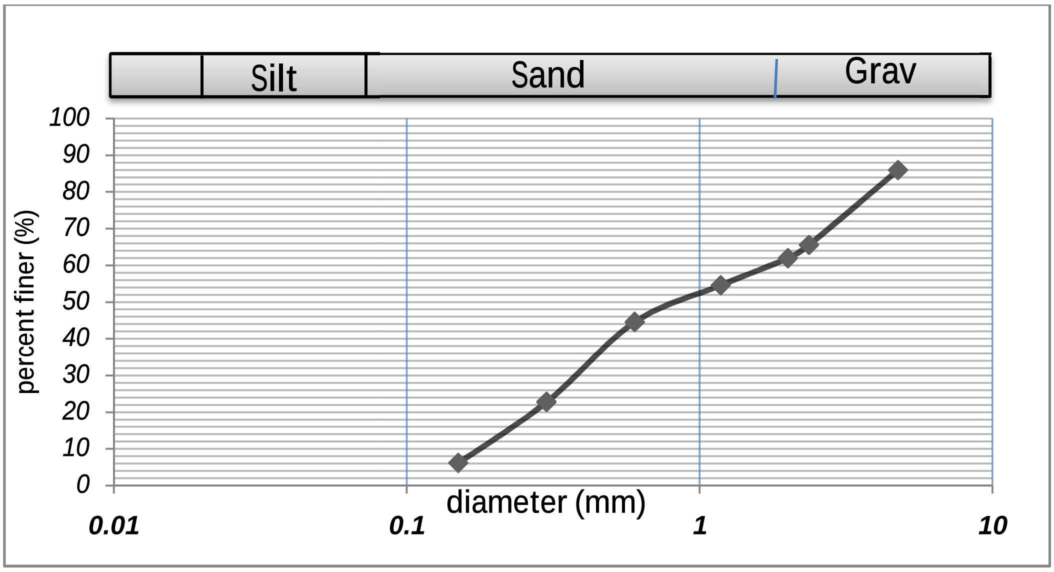


Fig .(1): flow chart program for experimental work.

2.1 Soil used:

In this study, natural soil with 5% gypsum contamination brought from a region in Tikrit Governorate, was used as a backfill material. The same soil mixed with additional gypsum as to form the base soil for the concrete retaining structure and became 25%, 40% and 60**%.**

The large scan of ratios would envision the full scale behavior of gypsum content. High percentages of gypsum content do exist in Iraq such as Tickret and Beijy regions(in the middle-northern region of Iraq). In these landscapes gypsum content can be found as high as 70%, especially in the near surface soil[8]. It is worth to mention here that changing gypsum content in soil is only to reflect the behavior of the retaining wall upon increasing amounts of gypsum in base soil. The classification tests conducted for such soil is summarized in **Figure (2).** It is classified as (SP) soil, according to USCS.



(a)

(b)

Fig .(2) (a) grain size distribution curve for soil used. (b) natural gypseous soil brought from Tikrit government (North of Iraq).

2.2 Model Prototype Description and set up:

The prototype is made from 6mmthick plastic sheets of longitudinal grooved, for stiffening the container sides and minimize the lateral movement mobilized from the soil. A sketch of the model and water feeding technique are shown in **Figure (3)..** The dimensions of the plastic container are(800 *500 *400mm). The gravity retaining wall is made from precast concrete. A glass piece was placed over the upper face of the concrete wall to ensure smooth surface for dial gage movement. It's prepared by placing concrete mix inside framework prepared and designed to take the shape of wall as shown in **Figure (4).** After 3 days, the wall is extruded, from the mold. The concrete wall, has a base width same as the width of the plastic box (less than width of box by about 3mm to allow free movement of wall without any friction or interference with the sides of model in addition to that to ensure free flow of water below the concrete structure [9]. The sides edges of the wall was coated with flexible water proof bituminous materials which work as a diaphragm to prevent water infiltrating from wall sides.

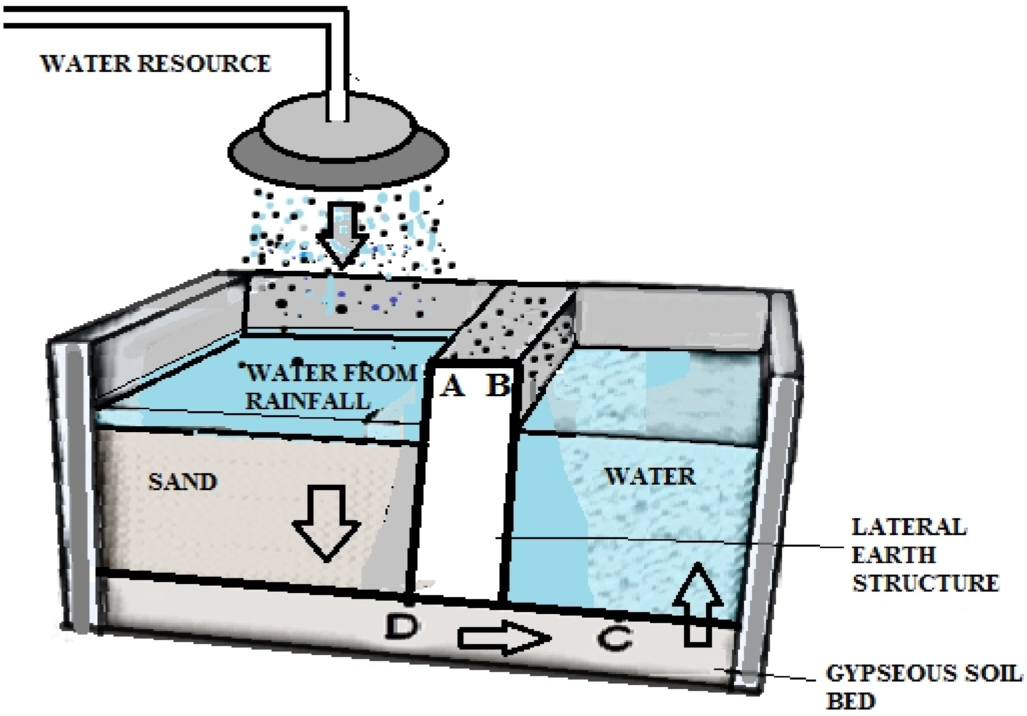
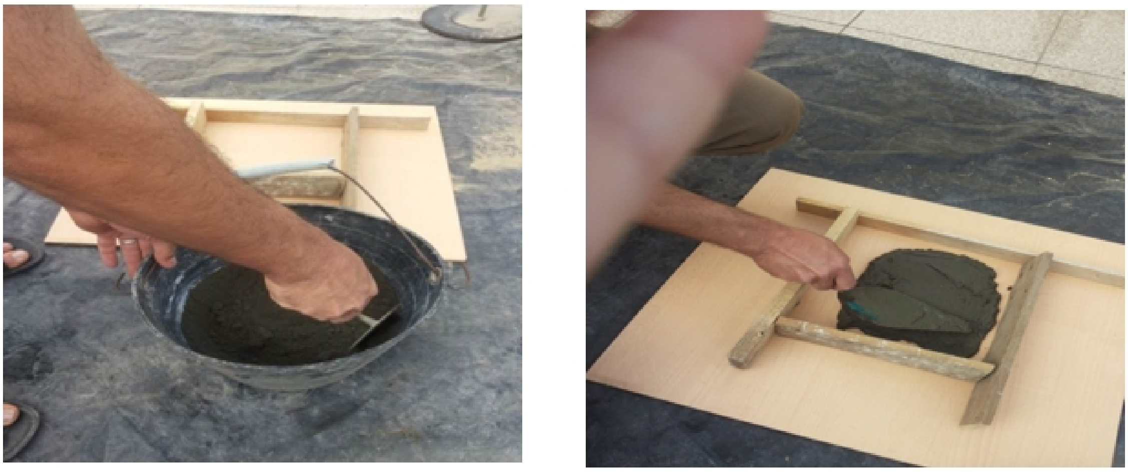


Fig .(3) sketch for laboratory model of lateral structure constructed on gypseous soil using a laboratory model constructed for this sudy.

a) preparation the framework for the Concrete retaining wall.



b) preparation of retaining structure by Placing concrete inside the framework.

c) Extruding the concrete wall from the framework and coating its sides with water proof bituminous material.

Fig .(4) preparation of concrete retaining wall for laboratory model tests.

2.3 Model preparation and testing methodology:

The soil used in this study is collapsible gypseous soil mixed thoroughly with 2.6% of water, so that it can receive little compaction. The gypseous soil is transferred to tank and dumped there in terms of three layers, each of 70 mm and each layer is given, as said, soil density=18kN/m^3. After that the concrete retaining wall is placed in middle of model. Sand without gypsum (pure sandy soil) is damped and placed as a backfill behind the wall with 11.4 kN/m^3 density. This density of sand was used to simulate the worst cases, when the presence of weak soil and so, the representation of the vertical and horizontal movement of the wall was more clearly and clarify the status of the failure of concrete structure retained this low density backfill. In addition to that it make easy for flow of water movement from top of backfill to bottom and the accelerate penetration of the water to bed gypseous soil layer.

In order to explain comprehensively the steps of model preparation for test are shown in **Figures (5).**

- After placing the base gypseous soil layer inside the stiffened plastic container and compacted to the required density ,the concrete wall structure was fitted at its place and coated its sides with the wall sides carefully by a water proof bituminous material, the backfill sand soil was placed and compacted to the required height.
- Two dial gauges were used to measure movements of the retaining wall, one is place vertically in order to measure the settlement of the wall, and another one is placed horizontally in order to measure the horizontal deflection of wall. The two dial gauges are fixed by magnetic holders and in two those are fixed magnetically to the large steel table.

The initial reading of dial gauges was taken, water is poured in the backfill side (behind the wall) using a sprayer to simulate the natural rainfall as shown in **Figure(6).** Dials readings with time are simultaneously recorded, so, two curves one for vertical settlement of retaining wall and other for horizontal movement of wall were prepared for each model test.

Fig .(5) preparation steps for the bed gypseous soil ,Compaction natural gypseous soil bed and placement of sand backfill and dial gauges fitting.

Fig .(6) wetting of soil by feeding water from a sprayer device, and starting test by taking the vertical and horizontal displacement with time.

It is customary to normalize the data so that it is well understood in terms of some specified dimension of wall. Thus the vertical settlement is normalized in terms of footing width or wall height (H). So, we have settlement is represented as Sv/B and wall movement in terms of (Sh/H). as shown in **Table (1).**

Table(1): Abbreviations and nomenclature adopted in this study.

H	B	Sv	Sh	Sv/B%	Sh/H%
Hight of retaining structure	width of retaining structure	Vertical movement of retaining structure	horizontal movement of retaining structure	vertical deflection%	lateral deflection%

The Sv/B and Sh/H are plotted with time in which time scale is represented in logarithmic scale and Sv/B and Sh/H are in arithmetic scale.

3. Results and Discussion:

Upon conducting triaxial tests on cohesion less soil, Lamb (1979) showed that strain required to achieve active and passive conditions may be inferred from the results of triaxial tests[10], and his important conclusion that, Very little horizontal strains, less than 0.5% is required to reach the active state, for sands[10]**.** The results apply where the initial condition is not Ko condition. If initially $s'h/s\acute{v} \neq$Ko, then somewhat different strains will be required to reach the limiting condition and since most field problem involving retaining structures are plane strain situations, the triaxial data are only indicative of those applicable to actual field problems.

Full scale models were conducted by Terzaghi (1943)[5]. He demonstrated the active and passive theories by very careful tests. In these tests the walls were held against horizontal movement as the back fill was placed and the thrust against the wall was measured. The thrust was greater than the active thrust. Then the wall was released and permitted to move horizontally or rotate. After a movement of the top of the wall equal to only 0.001 times the height of wall, thrust was dropped to its theoretical active value. This is very small amount of movement with angular rotation of only 6%. On the other hand Bowles, J. (1997)[11] and Das, B. M.[12]. presented a table showing amount of horizontal translating to motive to the Ka condition,

From the foregone discussion it is intended to compare the movement of retaining wall with standard movement of retaining wall according to Ranking and Coulomb theories of active and passive states, i.e., the k_o, Ka and Kp conditions of soil. And as said before that careful studies conducted by Terzaghi about one century ago revealed that a horizontal movement of 0.001 times height of wall (a displacement of 0.001H) is only enough to show up the Ka condition.

3.1 results of lateral earth structure resting on untreated gypseous soil:

The results of untreated gypseous soil with 60% gypsum content are shown **Figures (7)** and **(8).** In these figures the displacement of retaining wall is presented in normalized form with time in minutes. The vertical settlement is shown in terms of settlement/ width of wall.

In **Figure (7)** it can be seen that the total angular rotation wall(Sh/H)% is 2.3% from the early start of soaking process and it is above the Terzaghi limit of reaching the Ka condition which is proven to be 0.001. The final number reached after about one week of soaking process is about 2.88% which is ten times the rotation needed for soil to be transferred from "at rest" to active state. Thus it is concluded by authors that rotation of retaining wall founded on 60% gypseous soil, cannot be calculated in terms of coulomb and Rankin theories since this movement is not solely due to the active state (although it is included into) but due to as well the collapse settlement of soil below wall. Due to the small (relatively) height of wall, this low rotation is expected. Although the gypsum content in base soil is considered terribly high.

In **Figure (8)** the vertical settlement of retaining wall quickly increases to about (Sv/B) % value of 2.7% and remains throughout that level approximately to end of test. At end of test and that is about one week later, uneven movement took place in terms of up and down movements in the level (Sv/B)% of 0.027. This trend of behavior is attributed to uneven collapse settlement of the base gypseous soil with 60% gypsum content. This behavior may attributed to high dissolution of gypsum particles which happened after one week because of leaching of gypsum particles and cavities below the wall may happened which cause severe settlement and sudden collapse.

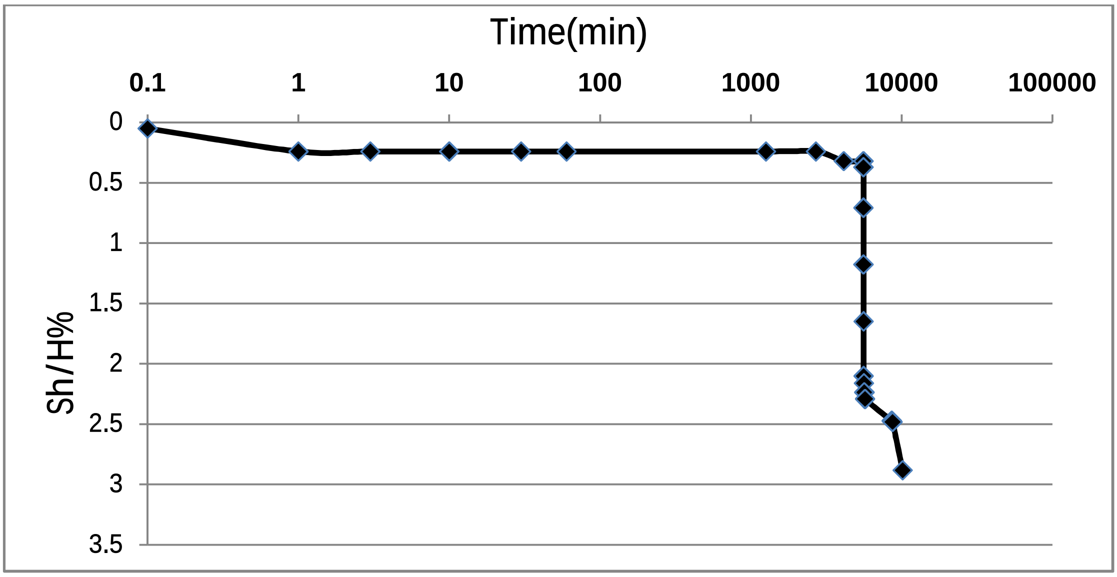


Fig .(7) Time – Settlement relationship for retaining wall model embedded with 60% gyp. Soil layer (horizontal strain).

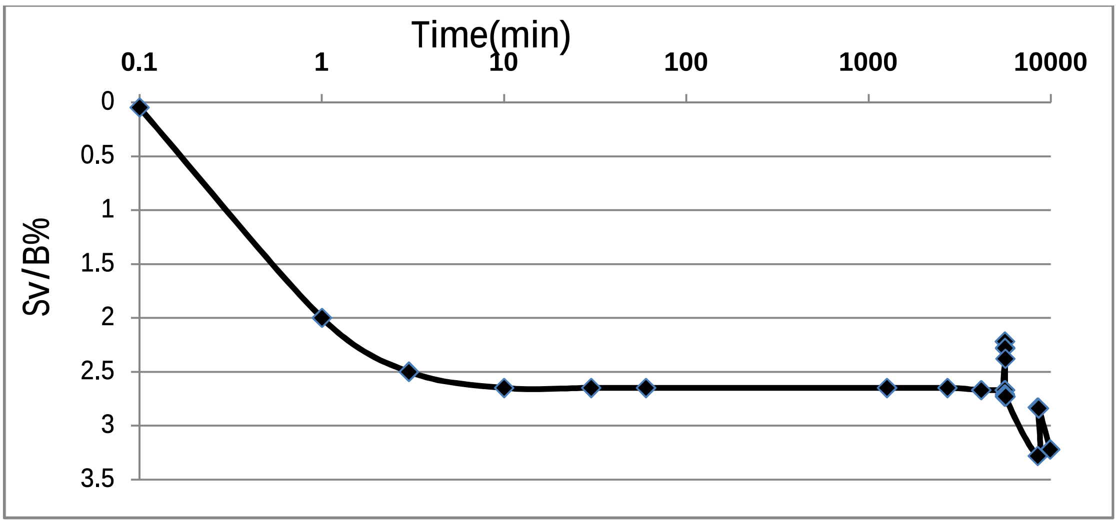


Fig .(8) Time – Settlement relationship for retaining wall model embedded with 60% gyp. Soil layer (vertical strain).

3.2 Results of lateral earth resting on untreated soil, with 5% gypsum content:

In **Figure (9)** and **(10)** very low amount of gypsum content is used namely 5% of soil dry weight. These two extreme boundaries of gypsum content, very high (60%) and very low (5%) are taken into account just to simulate actual condition that may encounter a civil engineer, now before going further into discussion, a general look at those two figures shows too much fluctuation in data recording for both horizontal and vertical movements. In order to explain these data, refer to the sketch of the retaining wall shown in **Figure (3):** At point A the dial gauge measuring the vertical movement of retaining wall is installed by fixing it to large steel table. At point B the dial gauges measures the horizontal movement of wall is installed and fixed as in the case of the vertical movement. If visualize that tip C settles alone downwards due to uneven collapse settlement then dial gauge at B will record positive movement of wall while that at tip A may measure zero settlement or may even record an upward movement if the center of rotation is at point between C and D.

On the other hand, if we have a settlement under point D only while point C remains still (again due to uneven settlement) then dial gauge at A may record a positive downward settlement while dial gauge at B may give negative records. In other words, due to uneven and differential collapse of retaining wall these fluctuations in curves of **Figures (9)** and **(10)** are attributed to the movement of retaining wall under collapse settlement which in turn depends on the location of center of rotation between points C and D. It is worth to mention here that the foregone explanations agree well with time of fluctuations.

The relation of both (Sh\H)and(Sv\B), with log time, start both at approximately same frame as can be seen clearly in figures. So these figures lead to a fact that collapse settlement of retaining wall founded over gypseous soil is totally not uniform and quite differential in nature unlike of most settlements. Its worth to mention that Bowles (1997)stated that convert retaining walls have a tendency to tilt forward because of the lateral earth pressure[11]**.** But they can also tilt from base rotation caused by differential settlements. Occasionally, the base soil is of poor quality and with placement backfill (typically the approach fill at a bridge abutment) the backfill pressure produces a heel settlement that is greater than that at the toe, this difference causes the wall to tilt into the backfill[11]. If the Rankin active earth pressure is to form, it is necessary that the wall tilt forward. Unless the wall has a front batter it is difficult for it to tilt forward even a small amount without the tilt being noticeable. It may be possible to reduce the tilt by overdesigning the stem.

Figures (9) and **(10),**shows that the retaining wall begins its movement only after one hour of soaking .after that the wall begin to fluctuate in its horizontal and vertical movement and finally became a horizontal tilt of (Sh\H)0.25% which is still beyond the ka condition although it reaches a maximum value, during period of fluctuation, of 0.53% which is about five times the tilt strain required to motivate the ka condition. that small quantity of gypsum content (5%), can cause tilt action to retaining wall above the ka condition .

In **Figure (10)** the value of (Sv/B)% begins to settle down after about one hour of soaking process and continues at trend of behavior for about four to five hours then finally levels off at a value 2.5%. This is a rather small value of settlement ratio. On the other hand, if full scale model are considered, the settlement may sum up to be large in terms of real dimensions of wall.

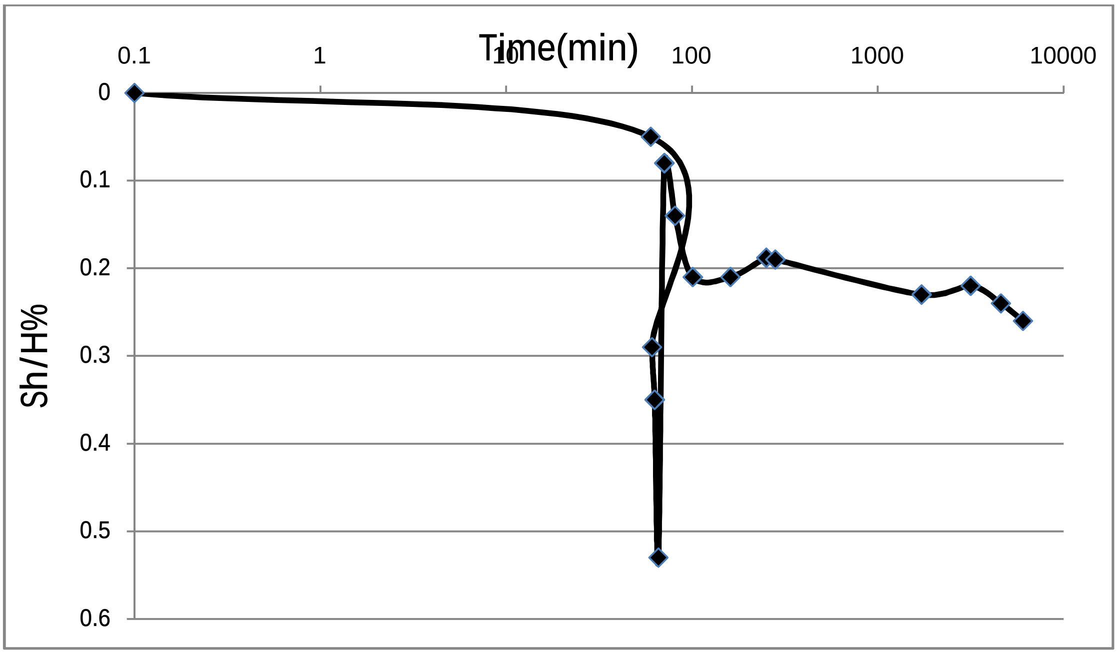


Fig .(9)Time-Settlement relationship for retaining wall model embedded with 5% gyp. Soil layer (horizontal strain).

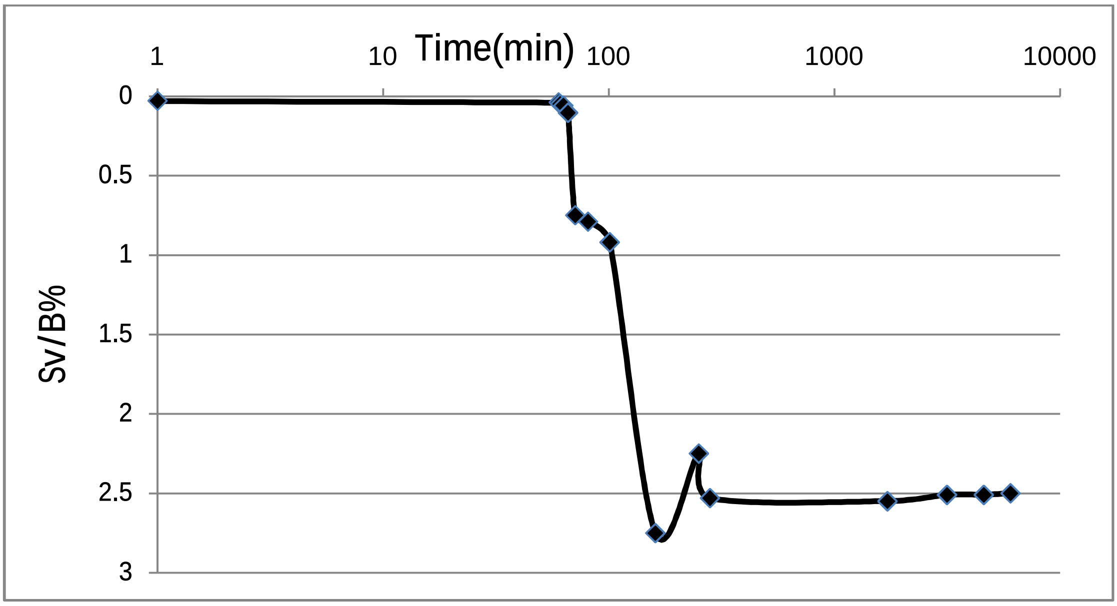


Fig .(10) Time – Settlement relationship for retaining wall model embedded with 5% gyp. Soil layer (vertical strain).

3.3 Results of lateral earth structure constructed on untreated soil with 25% gypsum:

Another model is built with gypsum content of 25%. The curves versus time for horizontal and vertical movements are show in **Figure (11)** and **(12).** In **Figure (11)** the horizontal movement started to show up drastically after about one day and reaches to a maximum value of 0.61%. This amount, as mentioned before ,is about six times the movement required for ka condition due to the large base settlement of gypsum soil base .but the curve became slight after about six days and the value of (Sh/H) is 0.45%. This residual value is still well beyond the ka value. When comparing time in which retaining wall starts to fluctuate in its movement in **Figure (9).** In **Figure (10)** which is quite similar to **Figure (9),** we see that after about one day the wall starts to settle down till a maximum value (Sv/B) of 1%, then finally levels off at a value of 0.25% this value is rather small but the tilt value is rather high.

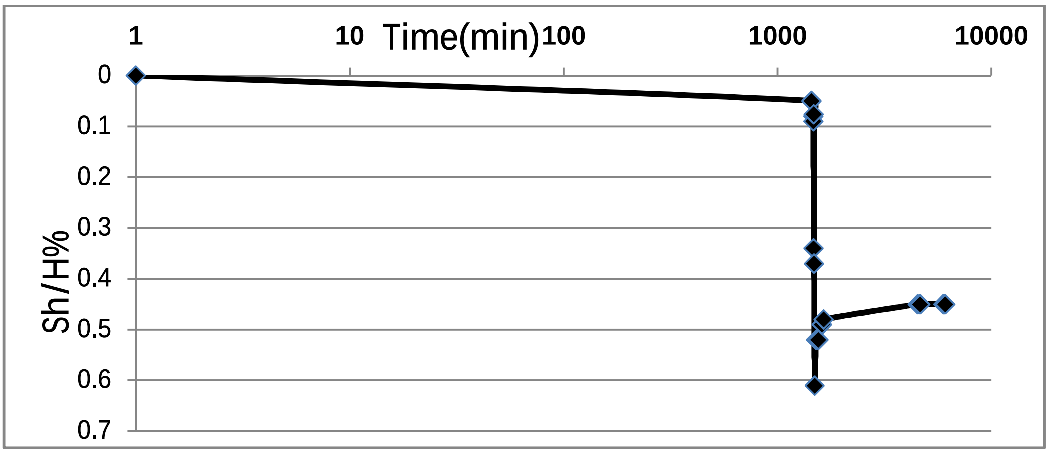


Fig .(11) Time & Settlement relationship for retaining wall model embedded

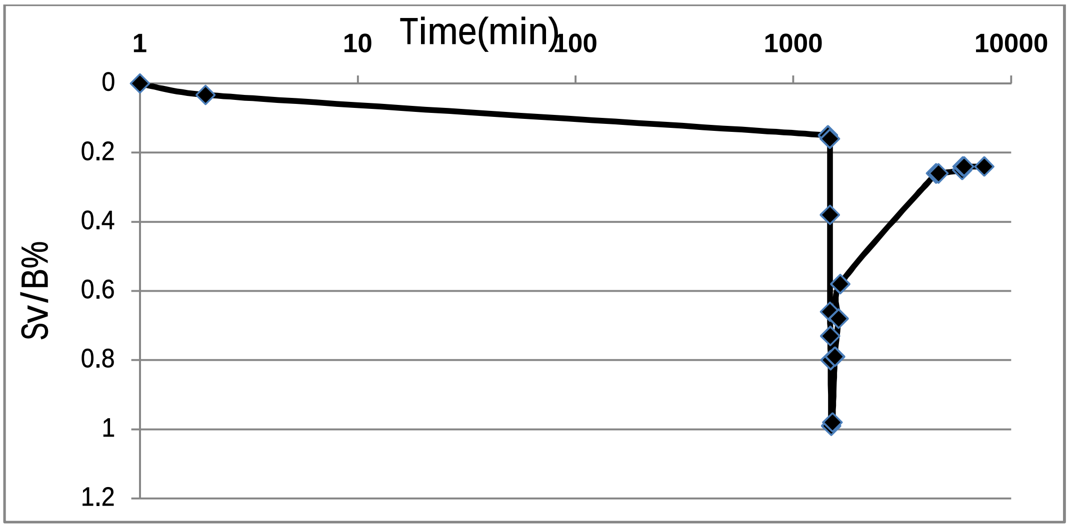


Fig .(12) relationship between time & settlement for retaining wall model embedded with 25% gyp. Soil layer (vertical strain).

3.4 Results of lateral earth structure resting on untreated and treated model with 3% cement addition:

Figure(13) shows the horizontal movement of retaining wall, while **Figure. (14)**Shows the vertical movement for untreated model with 40% gypsum, and Figure. (20)Shows both curves, together.

Figure.(15) shows the horizontal movement of retaining wall after mixing base soil with 3% cement. This percent of cement, was chosen because it was found that it is the most economical and effective, as mentioned before which gives a considerable strength for soil mix with. Above and below this percent of cement addition reduces strength[14]. while **Figure. (16)** includes the time-vertical settlement relation subjected on gypseous soil with 40 % gypsum content, treated with 3% cement addition.

Figures (17),(18) and **(16)** includes the Behavior of gypseous soil with 5%,25% and 60%gypsum content embedded below lateral earth retaining wall at dry and wet condition.

Figure (20) and **(21)** shows the behavior of lateral earth structure constructed on untreated gypseous soil bed, and treated with 3% cement dust, respectively.

The improvement in the soil embedded below the retaining structure are summarized in the monograph shown in **Figure(22).** They represent the maximum movement recorded for the two cases (treated and untreated gypseous soil bed). so the addition of cement to gypseous soil base has greatly reduced both the horizontal and vertical movements together. The reduction is shown in the following table based on the followings formula for improvement.

The improvement achieved by mixing the gypseous soil bed under the lateral earth heavy structure with cement, is very great and opens a promising future for dealing with such cases in sites as shown in **Table (2).**

Table (2) Improvement in settlement and tilt action of retaining wall bedded with 40% gypseous soil gained after the addition of (3% cement).

Gyp. soil layer below retaining wall	*Improvement in settlement**	*Improvement in Tilt action***
Mixing gyp. Soil with 3% cement	90%	25%

*%Improvement obtained in settlement $= \dfrac{(Sv/B)u - (Sv/B)T}{(Sv/B)u} \times 100$ **% Improvement in tilting $= \dfrac{(Sh/H)u - (Sh/H)T}{(Sh/H)u} \times 100$

(Where u and T denotes untreated and treated models)

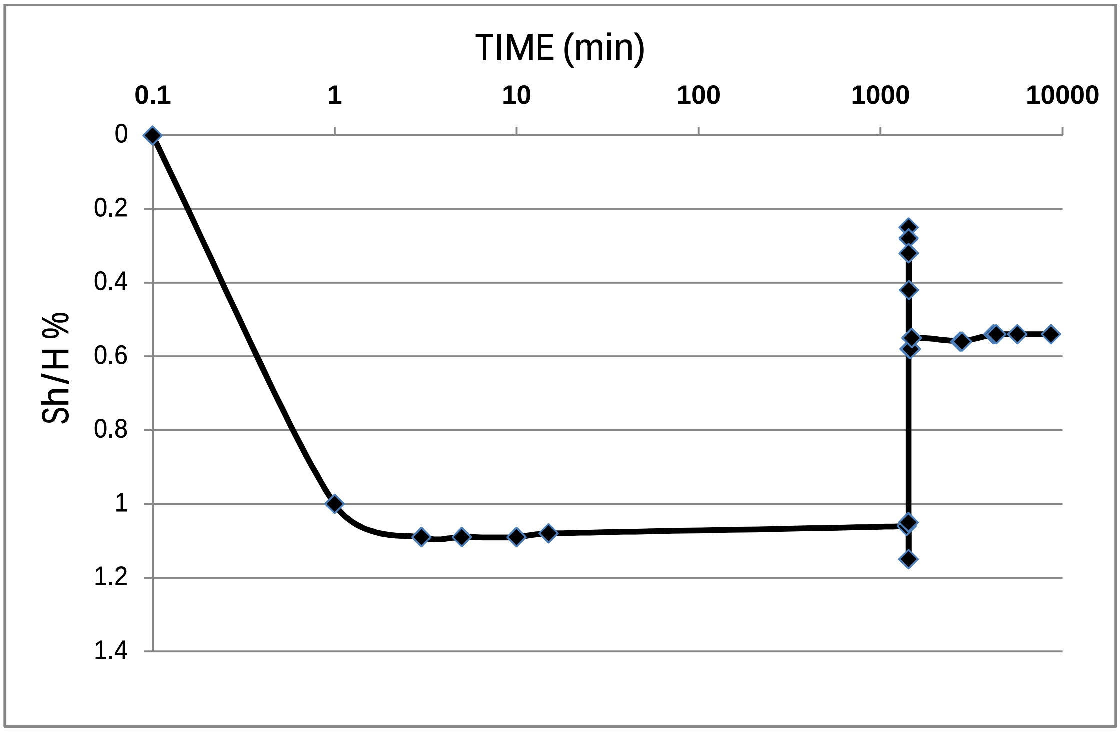


Fig .(13)Time & Settlement relationship for untreated retaining wall model embedded with 40% gyp. Soil layer (horizontal strain).

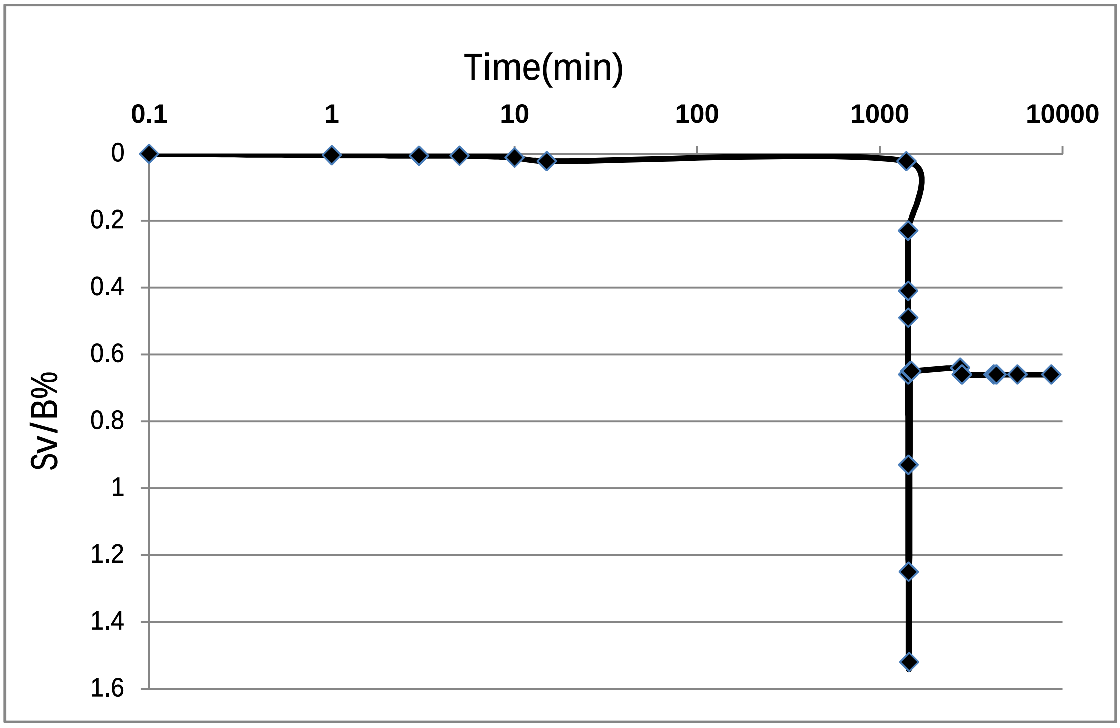


Fig .(14) Time-Settlement relationship for untreated retaining wall model embedded with 40% gyp. Soil layer .(vertical strain) .

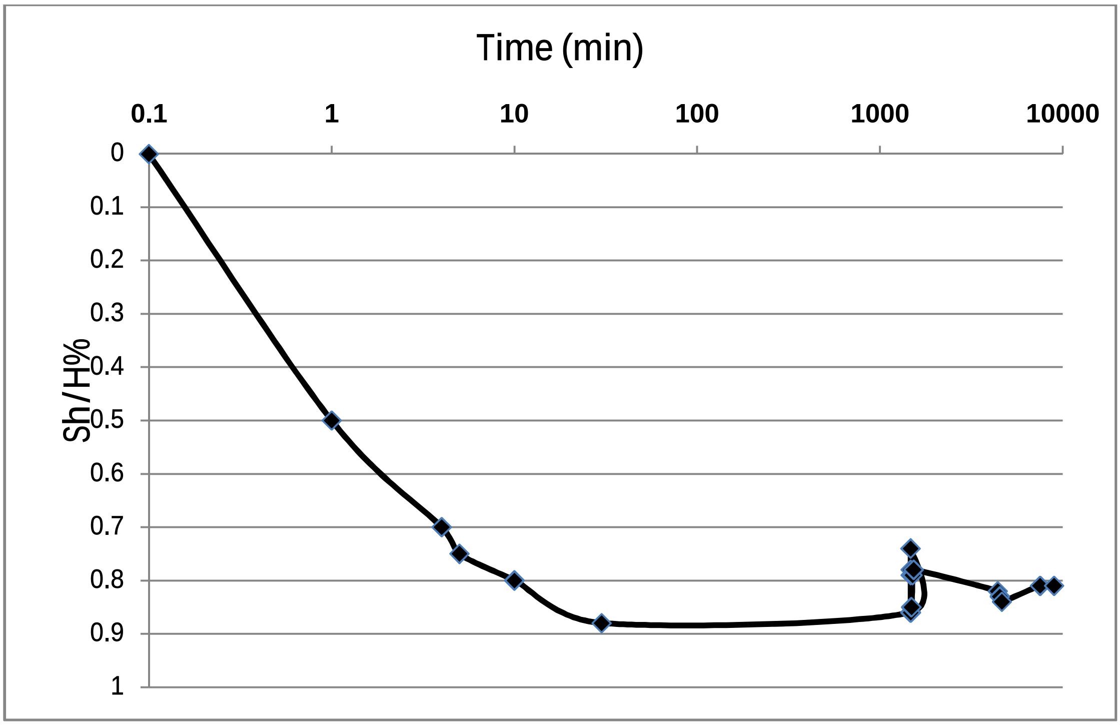


Fig .(15) Time- Settlement relationship for retaining wall embedded with treated gyp. Soil layer with (3%) cement adding by weight. (horizontal strain), gyp content=40%

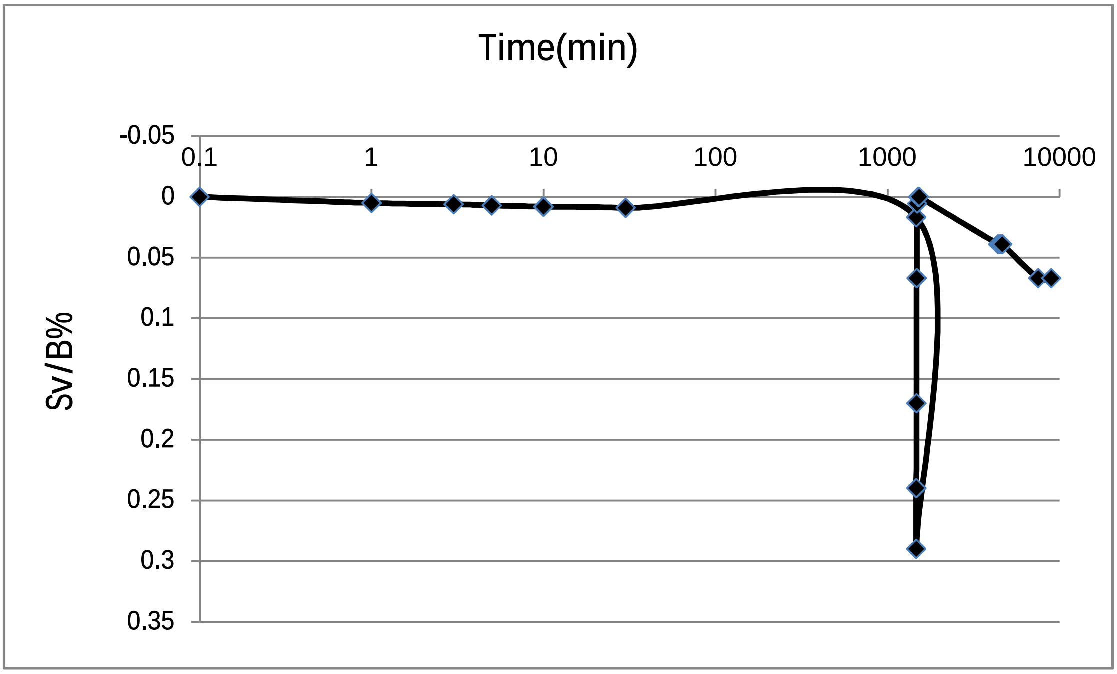


Fig .(16) Time-Settlement relationship for retaining wall embedded by treated gyp. Soil layer with (3%) cement adding by weight (vertical strain). gyp content=40%.

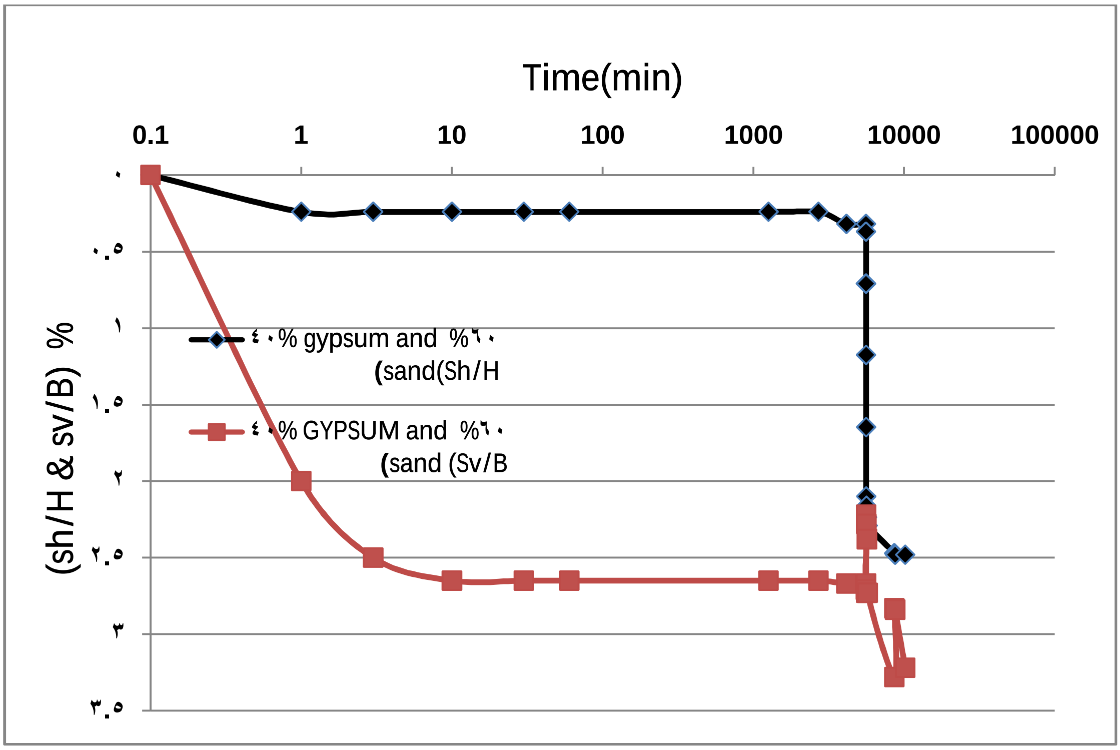


Fig .(17) Behavior of gyp. Soil With 60%gypsum content embedded below lateral earth retaining wall at dry and wet condition.

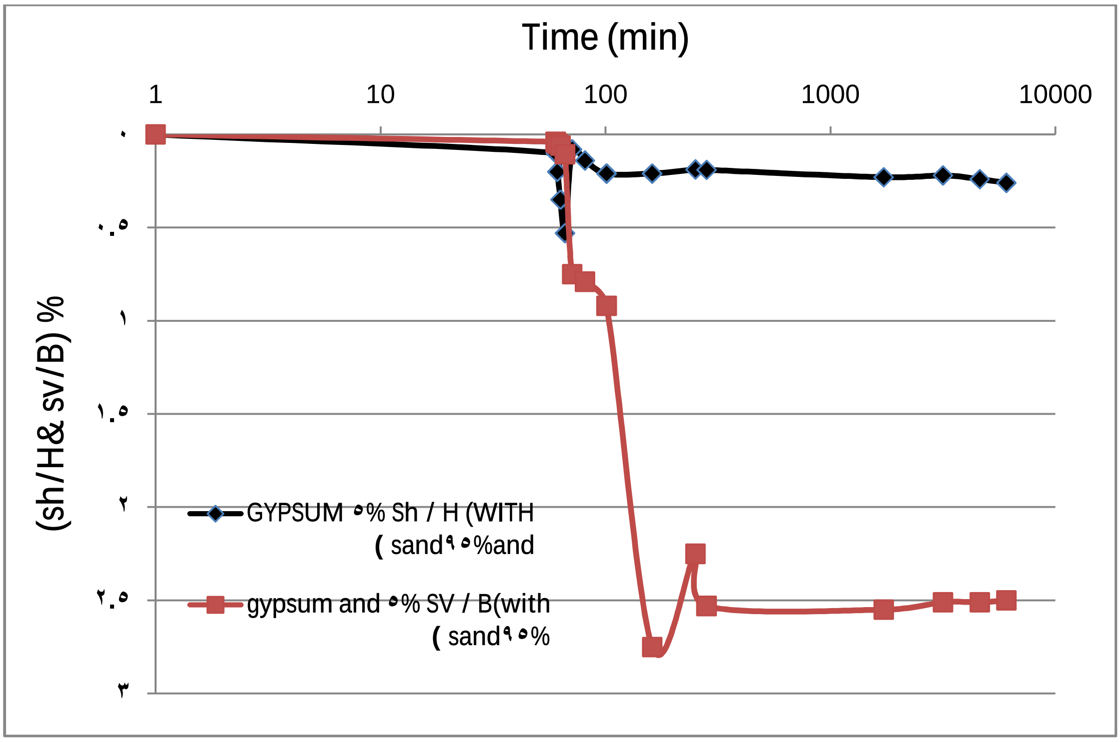


Fig .(18) Behavior of gyp. Soil with 5% gypsum content, embedded below lateral earth retaining wall at dry and wet condition.

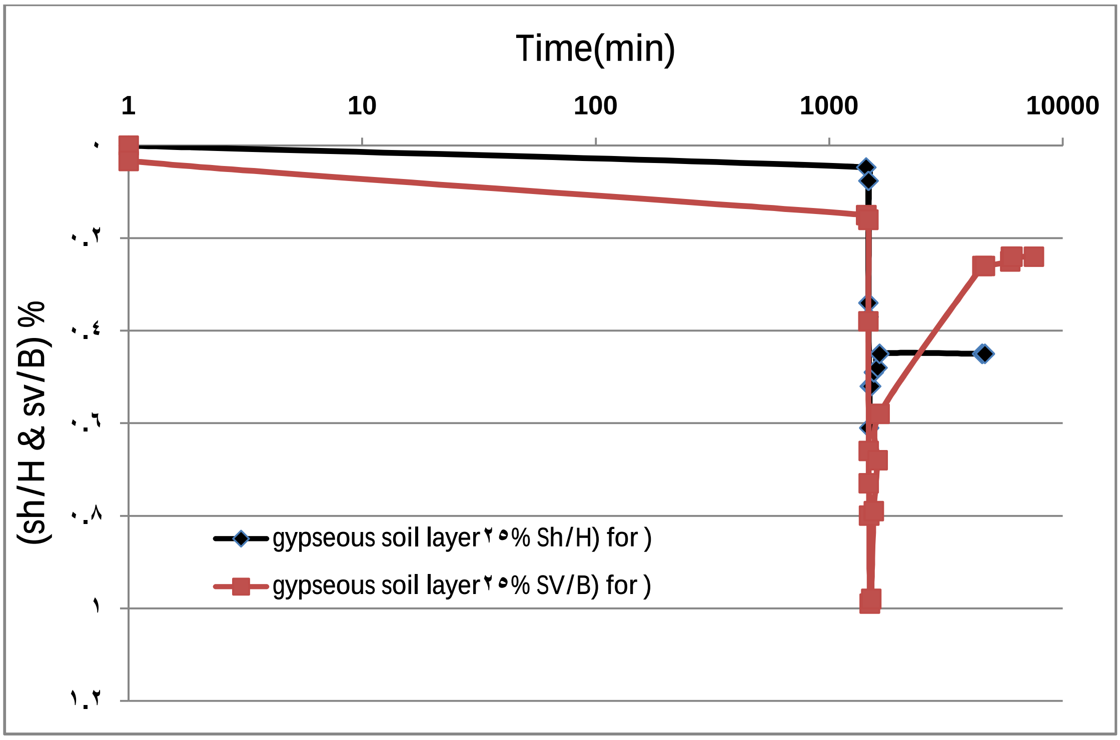


Fig .(19): Behavior of gyp. Soil with 25% gypsum content, embedded below lateral earth retaining wall at dry and wet condition.

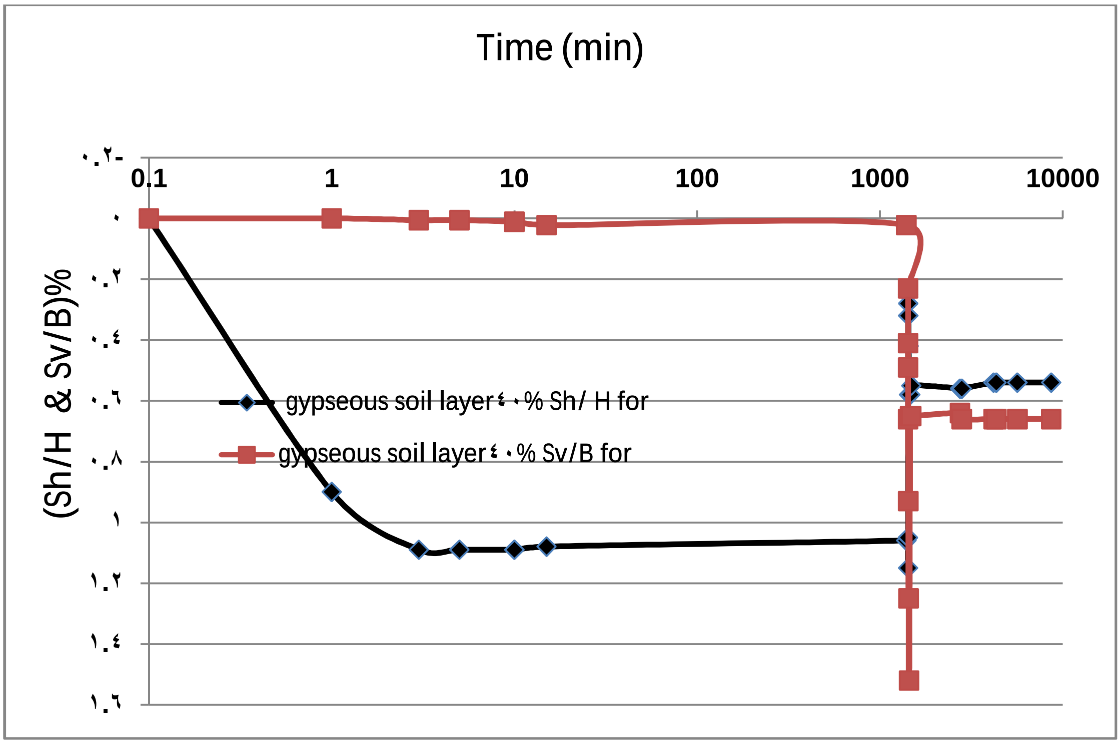


Fig .(20) : Behavior of gyp. Soil with 40% gypsum content, embedded below lateral earth retaining wall at dry and wet condition.

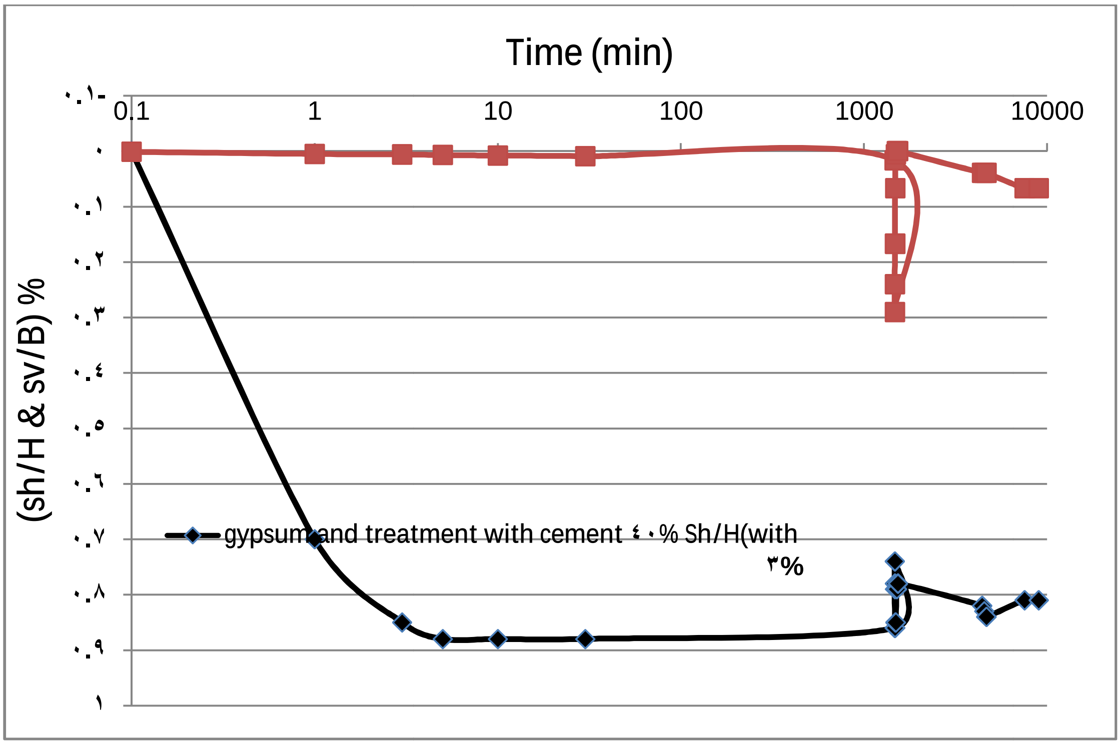


Fig .(21) Behavior of gyp. Soil with 40% gypsum content mixed with 3% by weight cement dust, embedded below lateral earth retaining wall at dry and wet condition

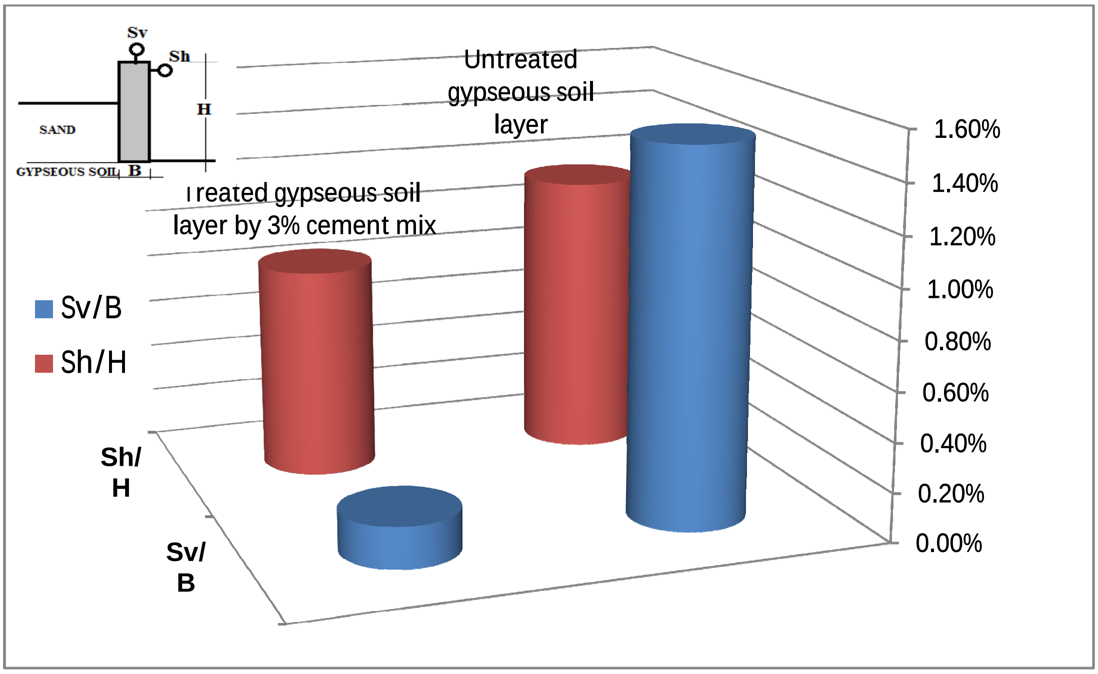


Fig .(22) Improvement in settlement and tilt action of lateral earth model bedded with 40% gypseous soil achieved by the addition of 3% cement, summarized from this study.

4. Conclusions:

From this study the author have concluded the following points hopping to be useful for those in concern:

1- Results carried on laboratory model tests, revealed that the movement of lateral earth wall through testing's is not uniform. the wall may settle forward or backward, move in toe faster than heel or the opposite . The vertical and horizontal movements of the concrete wall are totally random, that is due to the uneven settlement of wall resting on gypseous soil specially after 24 hour of continuous flooding of water because of fluctuation of water between soil particles and high dissolution of gypsum may have happened after this period due to leaching process and cavity formation below the heavy concrete wall.

2- It's worth to mention here that the danger from leaching is more than that from wetting of gypseous soil, which are observed in model tests after 1000 minutes of continuous flooding of water, this result agrees with many studies in this field **[8].**

3- The decision was made to use 3% percent of cement mix with gypseoues soils, which gave a considerable strength for stabilization. Above and below this range, the strength will be less. And the silica content in cement may contribute with the strength and give fewer results [14].

4- The improvement in vertical settlement for the retaining wall model reached more than 90%, after treating the embedded gypseous soil layer with 3% cement dust.

5- The improvement in horizontal settlement for the retaining wall model, reached 25%, after treating the embedded gypseous soil layer with 3% cement dust.

5. References

1. Commercial Installation Manual for Allan Block Retaining Walls (2011), (p. 13)

2. "Segmental Retaining Walls". National Concrete Masonry Association. 2008 http://web.archive.org/web/20080304073923/http://www.ncma.org/use/srw.html.

3. Ambrose J. (1991). Simplified Design of Masonry Structures (pp. 70-75.). New York: John Wiley and Sons, Inc.

4. Ching, F. D., Faia., R., S., & Winkel, P. (2006). Building Codes Illustrated: A Guide to Understanding the 2006 International Building Code (Building Codes Illustrated) (2 ed.). New York, NY: Wiley.

5. Terzaghi, K. (1934), *Large Retaining Wall Tests*, Engineering News Record Feb. 1, March 8, April 19.

6. Talal S and Abdullah Sabtan" Geotechnical and Geochemical properties of Al-Nekhaila Sabkha, south of Jeddah", Journal of king Abd Al-Aziz, Earth Sciences ISSN, 1999, Vol. 11, pp161-176. Publisher KAU-Scientific Publishing Center.(مكتبه افتراضيه)

7. **Al-Neami, M. M. (2010), "Improvement of gypseous soil by clinker additive". Eng. And Tech. Journal Vol. 28, No 19. (مكتبه افتراضيه)**
8. **Abed Awn, S. H. 2004,"Improvement of collapsible soils using locally manufactured reinforcement materials" Ph.D. Theses, Building and Construction Department, University of Technology.**
9. **Valenza, A. and Gillot, J. C. " Influence of groundwater on the degradation of irrigation soils in a semi-arid region, the inner delta of the Niger River, Mali.", Hydrology Journal ISSN, 2000, Vol.8, pp417-429.(مكتبه افتراضيه)**
10. **Lambe, T. W. and Whitman, R. V. 1979, Soil Mechanics, John Wiley and Sons. Inc. New York.**
11. **Bowles, J.,(1997). Foundation Analysis and Design, McGraw-Hill Book Company, New York.**
12. **Braja M. Das (2010)," Principles of Geotechnical Engineering", seven edition, Cen gage Learning.**
13. **Abid Awn, et al, (2012),"Improvement of Gypseous soil by Compaction and Addition of Cement", Journal of Engineering and Development, Vol. 16, No. 2, June 2012 ISSN 1813-1822.**
14. **Krishnaiah S. and Suryanarayana P. (2008), " Effect of Clay on Soil Cement Blocks", the 12th International Conference of Internationa Association for Computer Methodes and Advanced in Geomechanics (IACMAG), 1-6 October , 2008, Goa, India.**