THE SLUMP PROBLEM OF CELLULAR CONCRETE BLOCK (THERMOSTONE)

Montadher A. Muhammed

Department of Mechanics / Najaf Technical Institute

ABSTRACT

The research treats the problem of slump(as a type of creep) under self weight, that thermostone suffers during manufacturing process because the large dimensions and viscoelastic properties that the material has. Chemical composition and the percentage of added elements, especially the Gypsum and their effect on slump problem are studied using a practical method. The viscoelastic solution is applied here by Finite Element Method using the suitable model and taking with care the phenomena of aging. The viscoelastic solution is compared with the practical results for several stages of adding Gypsum.

Key word: Slump , Viscoelastic , Thermostone, Gypsum, Finite Element .

الخلاصه:

هذا البحث يعالج مشكلة الترهلSlump وهو تغير شكل المادة تحت تأثير الوزن الذاتي ، والتي تعاني منها كتل الثرمستون اثناء عمليات التصنيع،وذلك لحجم الكتلة الكبير نسبياً اضافة الى خاصية اللزوجة – المرونة (viscoelastic) التي تمتلكها المادة. يتضمن البحث نسب التركيب الكيميائي للمواد المضافة وخاصة مادة الجبس وتأثيرها على ظاهرة slump باستخدام أسلوب عملي. تم تطبيق حل عددي viscoelastic باستخدام أسلوب Finite Element مع استخدام الموديل المناسب والأخذ بنظر الاعتبار ظاهرة التقادم Aging. تم مقارنة الأسلوب النظري مع النتائج العملية لمراحل مختلفة من إضافة مادة الجبس.

(Baweja .S., Dvarak G.J. 1998)showed that linear slump in material occurs because of the viscoelastic phenomena , they proved that the increasing in viscosity, reduction in volume and evaporation of water will decrease the slump phenomena .

(Cilosani 2005) showed that slump is caused by formation and propagation of micro-crocks under loading in structure . He proved that the presence of moisture in material makes easy for propagation of defects and promotes slump at small loading.

(Cervera.E.2003) proposed a thermo-mechanical model for the short-and long-term mechanical behavior for a viscoelastic damaged model, and took into account the aging effects. He made a relation between slump and viscoelastic phenomena.

(Beweja.E 2000)showed how the mechanics of elastic composite material be adapted to predict the basic slump with aging due to hydration. He applied this method on concrete blocks which mainly contain the elastic elements represented by the aggregate (like lime stone) and the viscoelastic elements represented by the matrix of the structure.

Thermostone block deformations due to slump are not very large compared with its dimensions ,so that linear solution can be taken into account in the structure integrity analysis , however, deformations are enough to cause significant changes in the geometry of block , and this is out of the standard specification, so that equations of equilibrium will be formulated for the deformed configuration.

Viscoelastic behavior of thermostone blocks during manufacturing process needs viscoelastic solution, so that , the numerical solution (finite element method) will be extended from elastic to viscoelastic and choosing the suitable model.

Aging phenomena will be taken into account in the numerical solution due to the fact that the properties change with time , and the material becomes more stiff.

The practical side of the research includes making a number of samples with a different percentages of Gypsum, and consider the stability of block in front of slump phenomena, then testing the compressive strength to show the effect of this material on cracking and strength of samples.

A comparison was made between theoretical and practical work ,as well as, the results were compared with theoretical results obtained from software program (Ansys) in order to determine the efficiency of the procedure and to estimate the deviation taking place.

MATERIALS AND METHOD

Materials

Table 1 shows the different components percentages of thermostone before manufacturing and after drying .

It can be noted from this table that the material has a high percentage of water before drying process. This leads to a Viscoelastic behavior , this behavior continues to occur even after drying process, but in a decreased intensity.

The material here can be represented as a Viscoelastic solid , for this case , the more convenient famous model to represent is called "three parameter model" (Mark 1999) as shown in Fig 2, generally, this model is used to represent most standard linear Viscoelastic solids.

The most important properties for Viscoelastic material is the relaxation models G(t) and creep compliance J(t) which can be represented for three parameter model as (Assonnet 1974).

$$J(t) = \left[\frac{E_1 + E_2}{E_1 E_2} - \frac{1}{E_2} EXP\left(-\frac{E_2}{\mu} t \right) \right] \qquad (1)$$

$$G(t) = \left[\frac{E_1 E_2}{E_1 + E_2} - E_1 EXP\left(-\frac{E_1 + E_2}{\mu} t \right) \right] \qquad (2)$$

Generally these eqn. can be taken from special tables for most Viscoelastic material which getting from empirical sides (Hall 1985 Vol.1).

$$G(t) = 0.022 + 0.03e^{-0.25t} + 0.048e^{-0.5t} \qquad (3)$$

$$J(t) = 45.5 + 17e^{-0.5t} + 9e^{-0.75t} \qquad (4)$$

METHOD

A- Practical Side

Many samples were made with a different percentages of Gypsum (from 9% to 17%) , the slump phenomenon was studied for periods from (0 to 10 hr) .
These samples are studied for two cases (depending on manufacturing stages).

1-Fully supported base .

2- Unsupported base.

Then the deformation which occur in the sample will be measured practically by using simple instrument such as ruler and veriner caliper. .

A compression test was done on those samples after burning stage (final stage) to know the effect of Gypsum on the strength of material and standard specifications.

B- Theoretical Side (Finite Element Method)

Slump problem can be studied by using numerical method . The displacement based finite element method is one of such numerical procedures. The effectiveness of the method is due to its conceptual simplicity, assuming that the nodal point displacement of the finite element mesh completely specify the displacement in the body.

This finite element technique , which is demonstrated to provide an excellent analysis method for elastic case , has been extended to provide analysis capability for the Viscoelastic case in this research .

The relation of stress- strain for plane strain case are (Goerge 1976):

$$\varepsilon_{xx} = \frac{1}{E}(\sigma_{xx} - v(\sigma_{yy} + \sigma_{zz})) \qquad (5)$$

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - v(\sigma_{xx} + \sigma_{zz})) \qquad (6)$$

But :

$$\varepsilon_{xy} = \frac{2(1+v)}{E}\sigma_{xy} \qquad (7)$$

$$\upsilon = \frac{1 - \frac{2G}{K}}{2 + \frac{2G}{K}} \qquad (8)$$

$$E = \frac{9K}{1 + \frac{3K}{G}} \qquad (9)$$

Then from eqs.(5),(6),(7) the stress matrix {D} that contains material properties in term of relaxation (G) and bulk (K) module can be obtained .

Coordinate {X} of the node in term of local coordinate (ξ, η) and displacement field $\{\delta\}$ in isoparametric element is (Chandrupatla 1997) :

$$\{X\} = [N]\{X_{ii}\} = \begin{vmatrix} x(\xi,\eta) \\ y(\xi,\eta) \end{vmatrix} \qquad (10)$$

$$\{\delta\} = [N]\ \{\delta_i\} = \sum_{i=1}^{n} \delta_i N_i \qquad (11)$$

{N} is a matrix of shape function, which is a function of local coordinate ξ and η.

It is incorrect to vary only stress matrix {D} with time (the Quasi – static solution) since properties of Viscoelastic material varies with time, but it is convenient to differentiate this matrix with respect to time depending on the superposition theory of linear viscoelasticity and taken into account the aging effect which can be represented by entering time and temperature effect using WLF equation (Hall 1985 Vol.3) :

$$\log a_T = -\frac{c_1(T - T_S)}{c_2 + T - T_S} \qquad (12\ a)$$

T_s is the reference temperature (which represents material's specific constant for the position of the glass transition of the material).

C_1 , C_2 are constants relating to the choice of reference temperature.

$$\tau^{-} = a_T\ \tau \qquad (12\ b)$$

τ, τ^{-} is the current and past shifted time respectively

From the chosen model in Fig.2 and for the linear Viscoelastic material undergoes environmental changes it can be noted that the total stress is:

$$\sigma_{total} = \sigma_{elastic} + \sigma_{viscoelastic} + \sigma_{thermal} \qquad (13)$$

$$\{\sigma(t)\} = [D]\{\varepsilon(t)\} + \int_0^t [\dot{D}]\{\varepsilon(t)\}dt - 3\alpha K[T(x_1 t) - T(x_1 0) \qquad (14)$$

α - thermal expansion coefficient which is constant with time .

By minimizing the equation of potential energy eq. (14) can be solved.

The minimum energy M can be expressed as (Chandrupatla 1997):

$$M = \frac{1}{2}\int_v [\sigma(t)]\,\varepsilon^T(t)\,dv - \int_v [\delta]^T Fv\ dv - \int_s [\delta]^T Fs\ \ ds \qquad (15)$$

F_v : is the body force per unit volume

F_s : is the load of surface traction

For slump problem ,load vector can be represented as (Hinton 1977):

$$F_{gravity} = \rho\ V\ g \qquad (16)$$

ρ-density

V-volume

g-gravity constant=9.81 N / kg

By substituting eqns (14),(11) into eq. (15) and minimization with respect to nodal displacements the total potential energy can be written as :

$$\frac{\partial M}{\partial\left[\delta^e\right]^T}=0=\int_{ve} B^T DBdv\left\{\delta^e\right\}+\int_{ve} B^T D\left[\int_0^t\left\{\varepsilon(t)\right\}dt\right]dv-\int_{ve} N^T \rho Vg\,dv-$$

$$3K\alpha\int_{ve} B^T(T(X,t)-T(X,0))dv \tag{17}$$

Solving eq. (17) will give the values of displacements for all nodes in the structure of interest.

Results and Discussion

- Maximum slump occur in the center of block base for unsupported case, whereas, maximum slump for supported base occur in the top of block.

Table 2 show the experimental results which include relation between slump phenomena and the amount of added Gypsum for two cases (supported and unsupported base) .

From this table it can be noted that slump phenomena decreases with increasing Gypsum percentage, Gypsum quickly reacts with water present in thermostone structure to form solid stiff compound that bind thermostone and provides high dimensional stability as in the following reaction (Hall 1985 Vol.7):

$$CaSO_4\,.1/2H_2O + H_2O \longrightarrow CaSO_4\,.1.5H_2O + heat \tag{18}$$

This causes to drag most water quickly from structure and causes to reduce viscoelastic behavior.

Data of slump is plotted with time for each sample of thermostone as in Fig. 3

It can be noted from Fig.3(a,b) for each sample that slump decreases with increasing Gypsum percentage, as well as, slump rate $\frac{\Delta L}{\Delta t}$ is decreasing with time . This occurs because of aging phenomena (Hall vol.3 1985) , which can be classified here to a chemical aging indicating the chemical reaction between thermostone components especially Gypsum with water as in eq.(18), and a physical aging which occurs due to water evaporation . This lead the material to become more stiff with time.

The added amounts of Gypsum to the mix of thermostone must not affect strength of material, so that a compression test was done on a sample (100 x 100 x 100 mm) for the final product as shown in table 3.

From table3 it can be noted that the added amounts of Gypsum (from 9% to 17%)cause no significant difference in compressive stress.

In any way the percentage of Gypsum most not exceed 14% in order not to effect on the other properties of thermostone especially the continuity and humidity resistance.

Iraqi standard specification required a compression stress not less than 2 MPa for this type of thermostone (Iraqi standard specification No. 1441/2000).

The theoretical results of slump obtained from Viscoelastic solution can be listed in the table (4):

Comparison tables 2 and 43 show that the difference between practical and theoretical results is not very large, the error percentage is about 7% .

Another comparison with software (Ansys) will be made as shown in Fig.5 for unsupported base and Fig.6 for supported base.

Fig.(7) shows the deviation of theoretical results from practical results (unsupported base case) for 9% Gypsum.

ACKNOWLEDGEMENT

The Author would like to thank the staff of Najaf Company for Insulation Material for their support.

Table1*: Components of Thermostone

Component	Chemical Characters	Percentage %	
		Before Manufacturing	After drying for 10 hr.
Sand	SiO_2	25.3%	37%
Limestone Powder	$CaCO_3$	3%	4%
Gypsum	$CaSO_4.0.5H_2O$	9%	11.3%
Ordinary Portland Cement	$(CaO)/3(Sio_2)+1.2(Al_2O_3)+0.65(Fe_2O_3)$	20.2%	26.38%
Aluminums' Powder	Al	0.04%	Goes to vanish
Water	H_2O	40.38	19%
Clay(as impurities)	Kaolinite and Oxides	Less than (2-3)%	Less than 2%

* Information in the table are practical and taken from Najaf Company for insulation material.

Table 2: Practical Results of Slump Problem

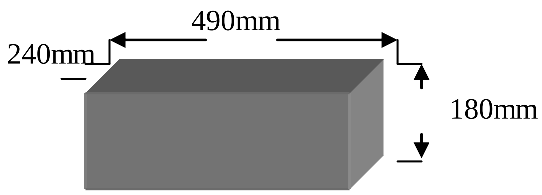
Density $\rho \quad kg/m^3$	Gypsum%	Maximum Slump mm at 10 hr — Manufacturing stages	
		Unsupported base base	Fully supported
751	9%	4.3	3.2
763	11%	3.3	2.7
782	13%	2.4	2.1
798	15%	1.4	1.2
817	17%	0.5	0.4

Table3: The relation between Gypsum percentage and ultimate compressive stress.

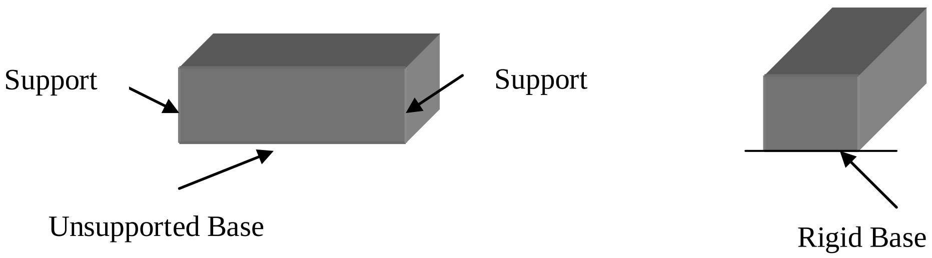
Density $\rho \quad kg/m^3$	Gypsum percentage%	Ultimate compressive stress (MPa) A sample of $(100\times100\ \times100)$ mm
540	9%	2
543	11%	2.05
554	13%	2.09
563	15%	2.07
569	17%	2.09

Table 4: Theoretical Results of Slump Problem

Density $\rho \quad kg/m^3$	Gypsum%	Maximum slump mm at 10 hr	
		Manufacturing stages	
		Unsupported base	Fully supported base
751	9%	4.8	4.7
763	11%	4.5	3.1
782	13%	4	2.4
798	15%	3.3	1.7
817	17%	1.5	1.2



(a)Thermostone Block



(b)

(c)

Fig 1: a-Thermostone Dimensions . b-Suspension Stage . c-Support Stage .

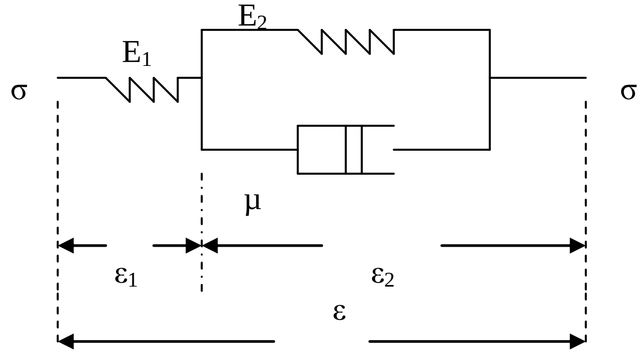
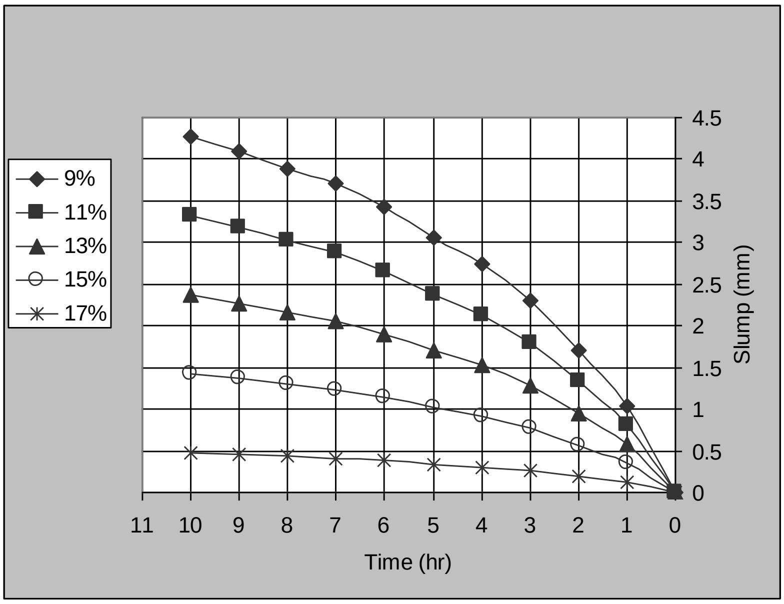
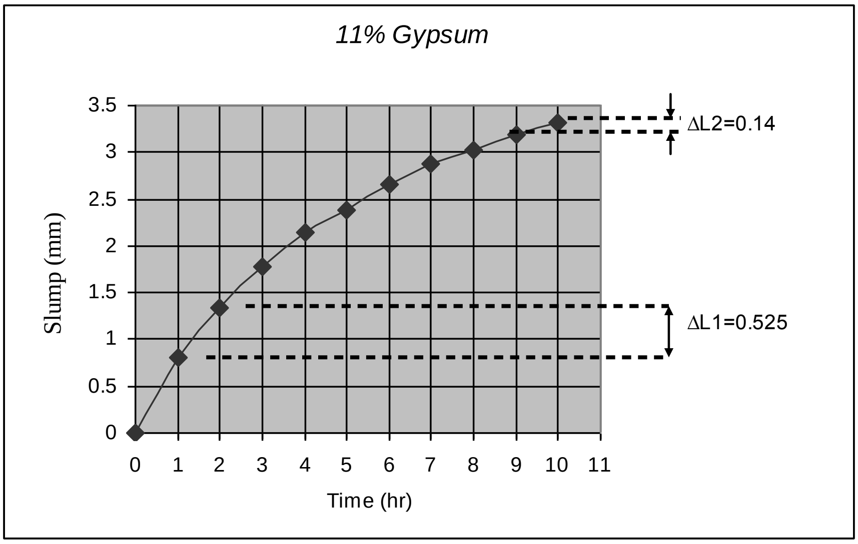


Fig 2. The three parameter model



(a)



(b)

Fig 3. Slump vs. Time (Practical) for unsupported base case
a. For several sample with a different percentage of Gypsum
b. Slump rate ($\Delta L/\Delta t$) decreased with time

Fig 4: Sample of thermostone (100 $\times$ 100 $\times$ 100) mm for compression test

(a) 3-Dimentional View

(b) 2-Dimentional View

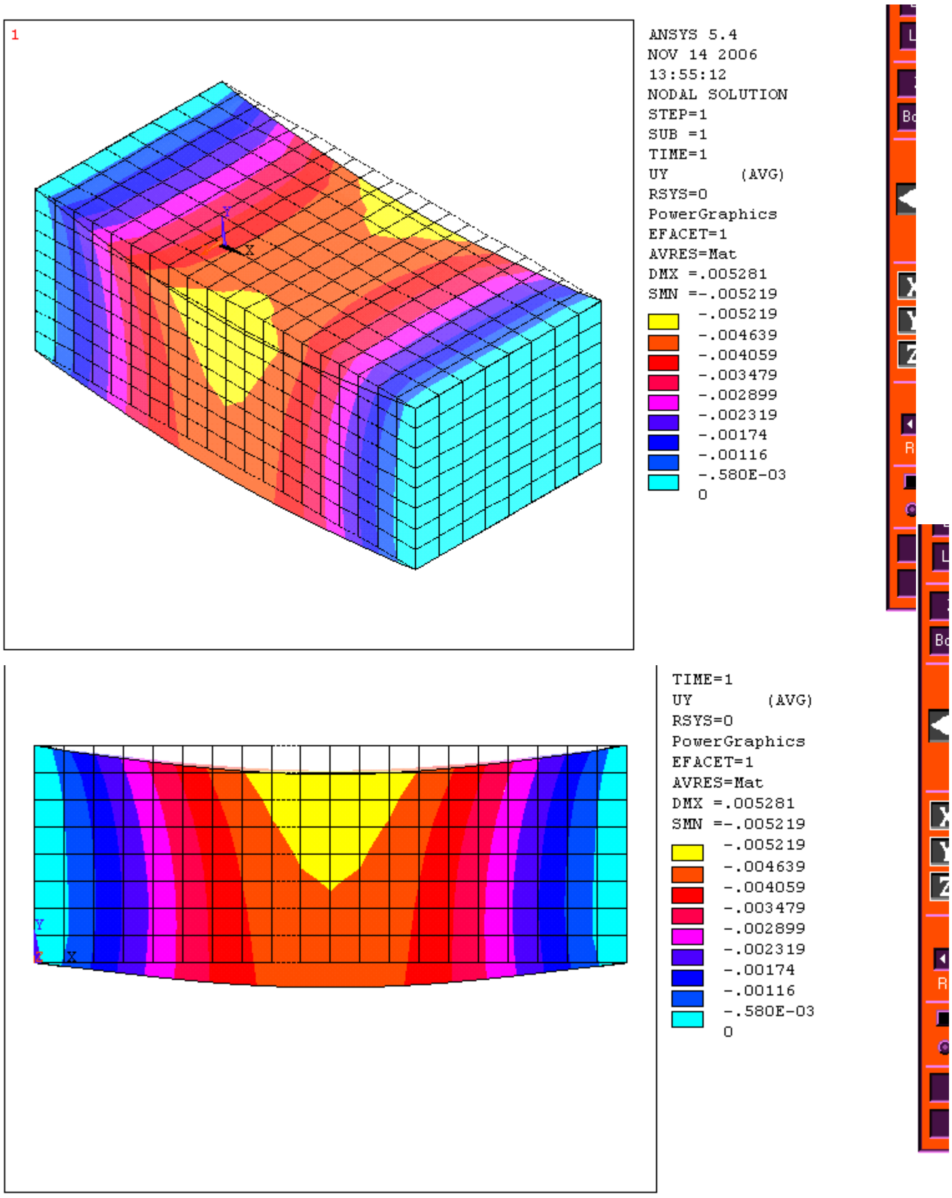
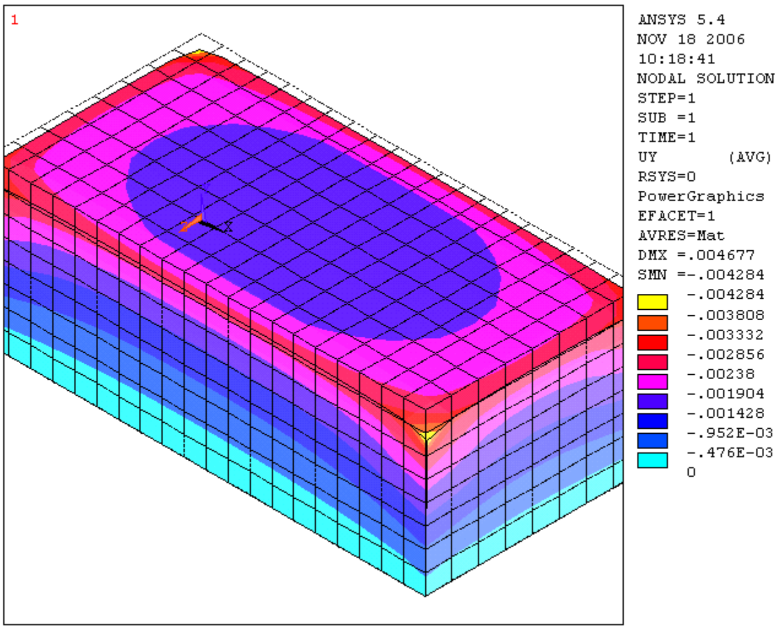
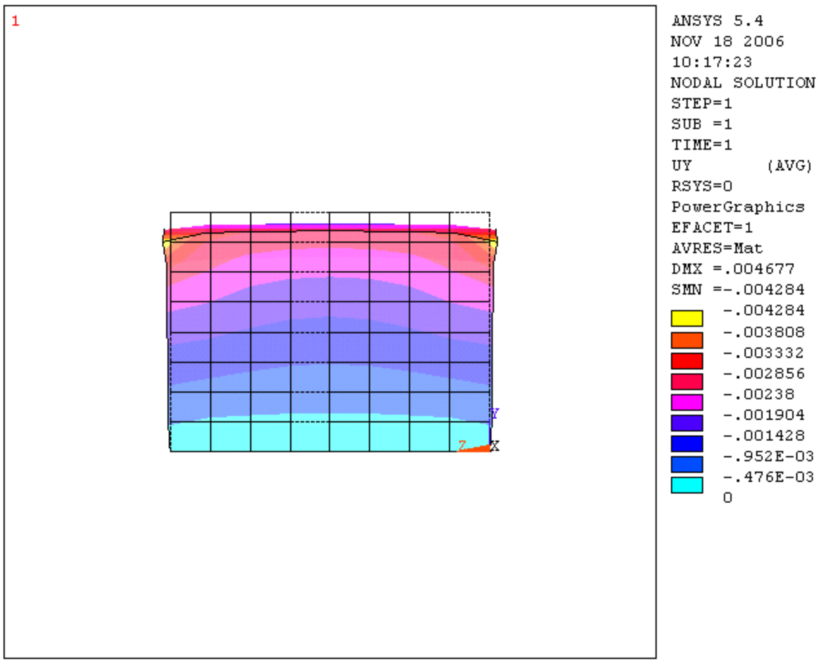


Fig.(5): Results of slump from software (Ansys) for 9% Gypsum (unsupported base case).



(a) 3-Dimentional View.



(b) 2-Dimentional View.

Fig 6: Results of slump from software (Ansys) for 9% Gypsum (supported base case).

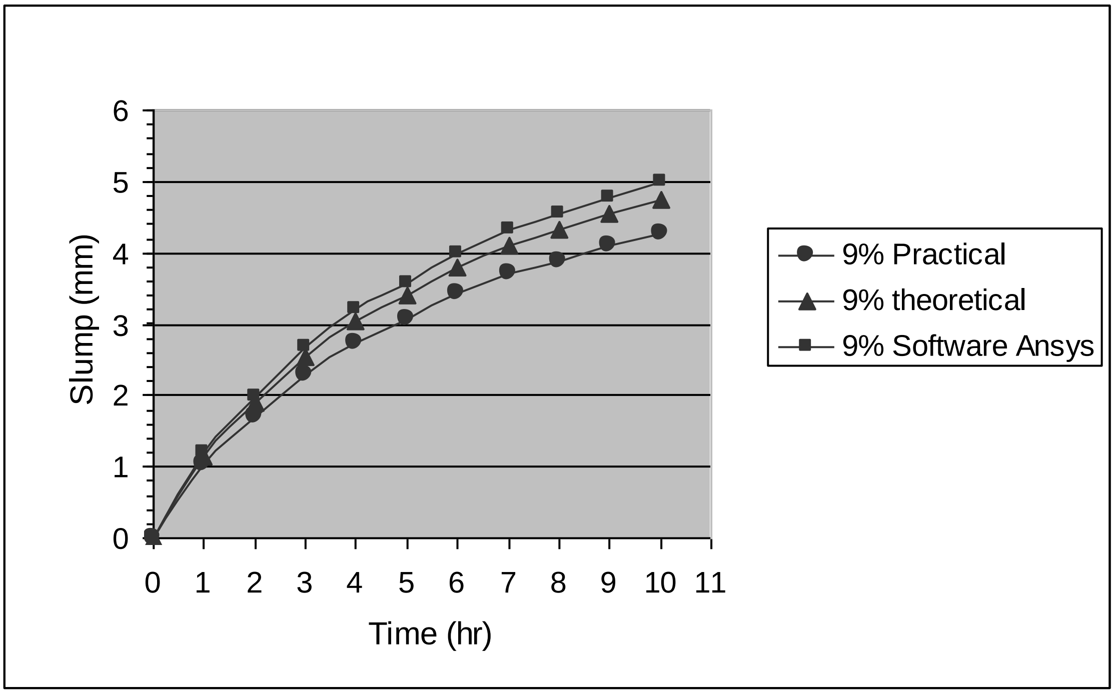


Fig.(7): The deviation of theoretical results from practical results (unsupported base case) .

REFERENCES

Bawejas,Bazant Z.P, "Triaxial composite model for basic creep of concrete", Journal of Mechanical and Materials Engineering ,Vol. 145,No.4,pp201-217.

Bawejas, Dvorak G.J. " Production of Creep and Temperature Effect in Concerts Structure ", Journal of Mechanical and Materials Engineering,Vol.124, No.9, 1998 , pp-959-965.

Cervera, E. "Creep of Viscoelastic material ", Journal of Mechanical and Materials Engineering , Vol. 137, No.6,2003, pp117-124.

Cilosani K.H,. "The effects of moisture and micro-crack on creep", Journal of Mechanical and Materials Engineering , Vol 137,No,5 2005,pp 223-231.

E. Hinton. D.R.J. Owen ,Finite Element Programming, Academic press Int. Ltd. London, U.K. , 1977.

Goerge E. Dieter , Mechanical Metallurgy, Kosaido printing co. Ltd . ,Tokyo . Japan 1976 .

H.Assonnet “Buckling behavior of imperfect elastic and linearly viscoelastic structures, Int. J. Solids and Structures ,Vol .74, NO. 10 pp755 – 784 , 1974.

I. H. Hall , Viscoelasticity , Encyclopedia of polymers science and Engineering , vol. 1, pp595– 610 , Kosaido printing co. Ltd . ,Tokyo . 1985 .

I. H. Hall , Viscoelasticity , Encyclopedia of polymers science and Engineering , vol. 3, pp 417– 433 , Kosaido printing co. Ltd . ,Tokyo . 1985 .

I. H. Hall , Viscoelasticity , Encyclopedia of polymers science and Engineering , Vol. 17, pp608 – 609 , Kosaido printing co. Ltd . ,Tokyo . 1985 .

M. Hilimi ACAR, "Viscoelastic Behavior of Blocks Used in Construction" , Turkish J. Eng. Sci., No 26 , pp 419-427 ,2002

Mark.C. Andre , Mechanical behavior of materials , prentice Hull , Inc , New York , 1999.

T.R. Chandrupatla , A.D. Belegundu, Introduction to finite element in engineering , Bombay , India, 1997