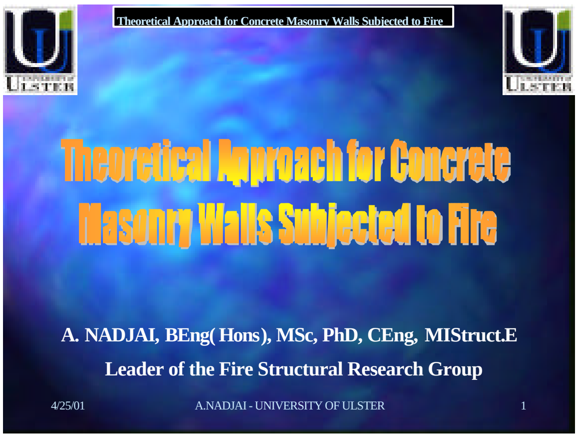

Theoretical Approach for Concrete Masonry Walls Subjected to Fire

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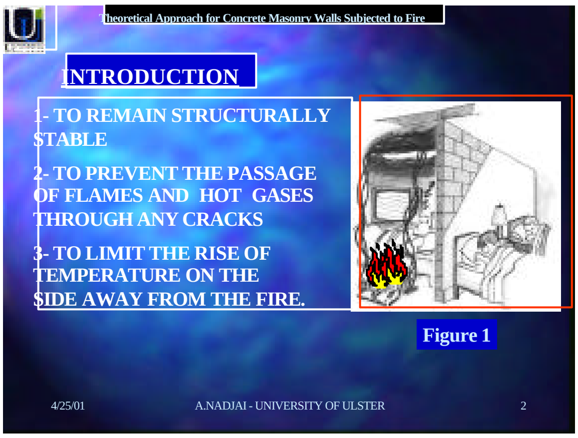
Leader of the Fire Structural Research Group



Theoretical Approach for Concrete Masonry Walls Subjected to Fire

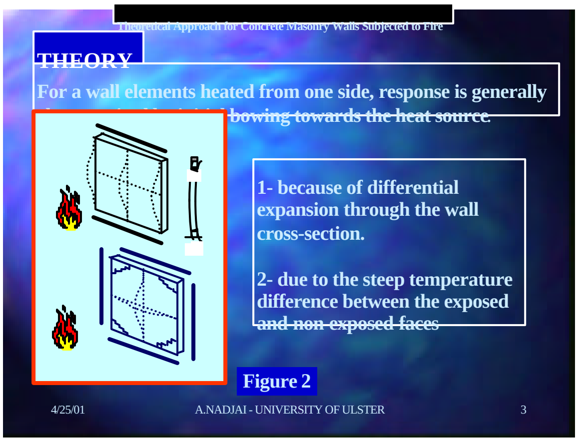
INTRODUCTION

1- TO REMAIN STRUCTURALLY STABLE

2- TO PREVENT THE PASSAGE OF FLAMES AND HOT GASES THROUGH ANY CRACKS

3- TO LIMIT THE RISE OF TEMPERATURE ON THE SIDE AWAY FROM THE FIRE.

Figure 1



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THEORY

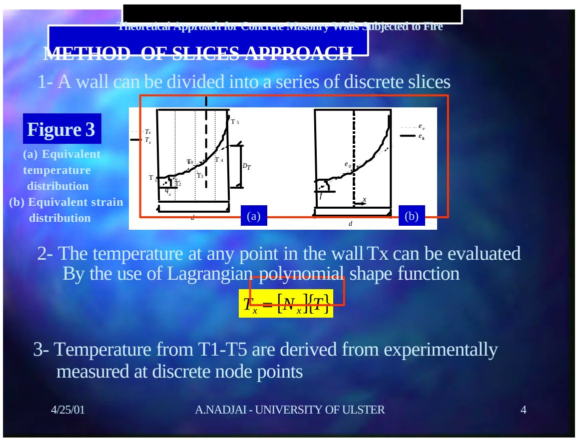
For a wall elements heated from one side, response is generally

bowing towards the heat source.

1- because of differential expansion through the wall cross-section.

2- due to the steep temperature difference between the exposed and non exposed faces

Figure 2



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METHOD OF SLICES APPROACH

1- A wall can be divided into a series of discrete slices

Figure 3

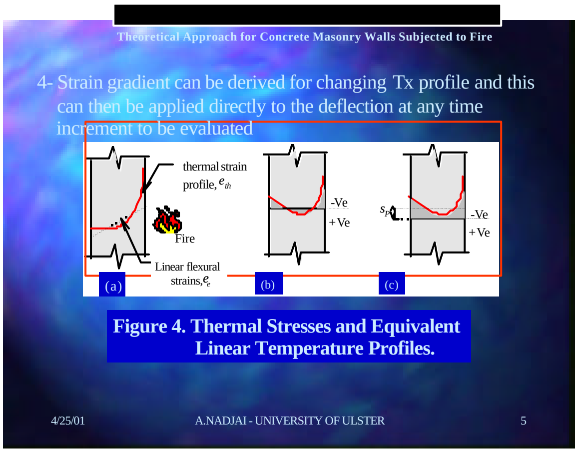
(a) Equivalent temperature distribution

(b) Equivalent strain distribution

2- The temperature at any point in the wall Tx can be evaluated By the use of Lagrangian polynomial shape function

$$T_x = [N_x]\{T\}$$

3- Temperature from T1-T5 are derived from experimentally measured at discrete node points



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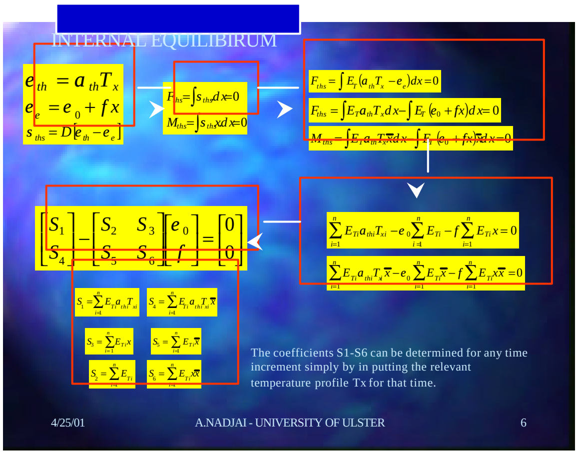
4- Strain gradient can be derived for changing Tx profile and this can then be applied directly to the deflection at any time increment to be evaluated

Figure 4. Thermal Stresses and Equivalent Linear Temperature Profiles.



INTERNAL EQUILIBIRUM

$$e_{th} = a_{th} T_x$$
$$e_e = e_0 + f x$$
$$s_{ths} = D[e_{th} - e_e]$$

$$F_{ths} = \int s_{ths} d x = 0$$
$$M_{ths} = \int s_{ths} x d x = 0$$

$$F_{ths} = \int E_T (a_{th} T_x - e_e) dx = 0$$
$$F_{ths} = \int E_T a_{th} T_x d x - \int E_T (e_0 + f x) d x = 0$$
$$M_{ths} = \int E_T a_{th} T_x \bar{x} d x - \int E_T (e_0 + f x) \bar{x} d x = 0$$

$$\sum_{i=1}^{n} E_{Ti} a_{thi} T_{xi} - e_0 \sum_{i=1}^{n} E_{Ti} - f \sum_{i=1}^{n} E_{Ti} x = 0$$
$$\sum_{i=1}^{n} E_{Ti} a_{thi} T_{xi} \bar{x} - e_0 \sum_{i=1}^{n} E_{Ti} \bar{x} - f \sum_{i=1}^{n} E_{Ti} x \bar{x} = 0$$

$$\begin{bmatrix} S_1 \\ S_4 \end{bmatrix} - \begin{bmatrix} S_2 & S_3 \\ S_5 & S_6 \end{bmatrix} \begin{bmatrix} e_0 \\ f \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$S_1 = \sum_{i=1}^{n} E_{Ti} a_{thi} T_{xi} \qquad S_4 = \sum_{i=1}^{n} E_{Ti} a_{thi} T_{xi} \bar{x}$$
$$S_3 = \sum_{i=1}^{n} E_{Ti} x \qquad S_5 = \sum_{i=1}^{n} E_{Ti} \bar{x}$$
$$S_2 = \sum_{i=1}^{n} E_{Ti} \qquad S_6 = \sum_{i=1}^{n} E_{Ti} x \bar{x}$$

The coefficients S1-S6 can be determined for any time increment simply by in putting the relevant temperature profile Tx for that time.

DEVELOPED MODEL

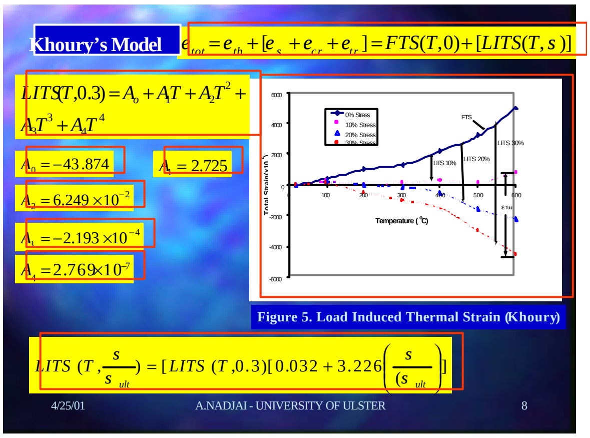
1- Concrete exhibits a large degree of creep when subjected to the combined effects of load and temperature.
2- Creep leads to relaxation of stress and can bring about an overall reduction in strain.

Andeberg's Model $e_{tot} = e_{th} + e_s + e_{cr} + e_{tr}$

$$e_{th} = -1.8x10^{-4} + 9x10^{-6}T + 2.3x10^{-11}T^3$$ (0 ºC < *T* < 700 ºC)

$$e_{th} = 14 \; x10^{-3}$$ (700ºC < *T* < 1400ºC)

$$e_{tr} = b_1 \frac{s}{s_{ult}} e_{th} \qquad e_{tr} = -2.35 \frac{s}{s_{ult}} e_{th}$$



Khoury's Model $e_{tot} = e_{th} + [e_s + e_{cr} + e_{tr}] = FTS(T,0) + [LITS(T,s)]$

$$LITS(T,0.3) = A_o + A_1T + A_2T^2 + A_3T^3 + A_4T^4$$

$A_0 = -43.874$ $A_1 = 2.725$

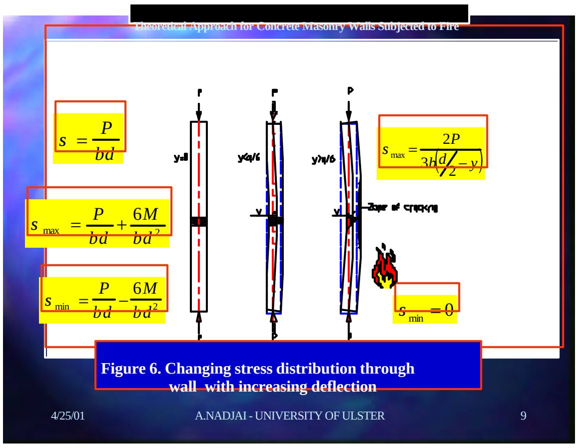
$A_2 = 6.249 \times 10^{-2}$

$A_3 = -2.193 \times 10^{-4}$

$A_4 = 2.769 \times 10^{-7}$

Figure 5. Load Induced Thermal Strain (Khoury)

$$LITS\left(T, \frac{s}{s_{ult}}\right) = [LITS(T,0.3)[0.032 + 3.226\left(\frac{s}{(s_{ult}}\right)]$$



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$$s = \frac{P}{bd}$$

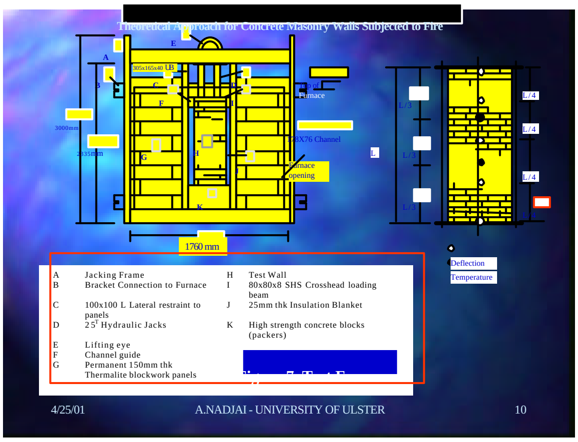
$$s_{max} = \frac{P}{bd} + \frac{6M}{bd^2}$$

$$s_{min} = \frac{P}{bd} - \frac{6M}{bd^2}$$

$$s_{max} = \frac{2P}{3b\left(\frac{d}{2} - y\right)}$$

$$s_{min} = 0$$

Figure 6. Changing stress distribution through wall with increasing deflection



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A	Jacking Frame	H	Test Wall
B	Bracket Connection to Furnace	I	80x80x8 SHS Crosshead loading beam
C	100x100 L Lateral restraint to panels	J	25mm thk Insulation Blanket
D	25^T Hydraulic Jacks	K	High strength concrete blocks (packers)
E	Lifting eye		
F	Channel guide		
G	Permanent 150mm thk Thermalite blockwork panels		

Figure 7. Test F

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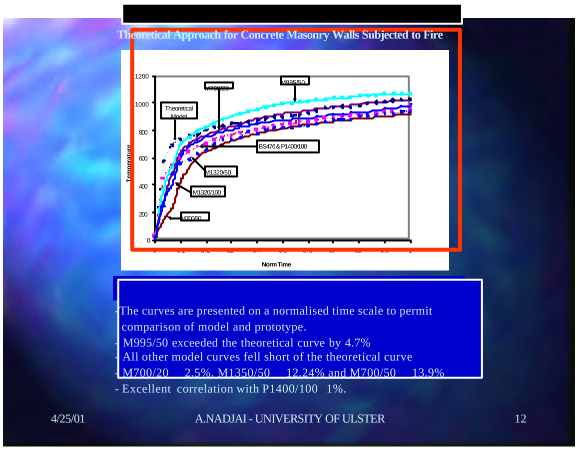
Wall Ref	Dimensions (mm)	Load (kN)	y (t=1.0) (mm)	y max (mm)	Time to failure
P1400/100	1400x425x100	100	10.6	10.6	Stopped t=1.0
M700/50	700x425x50	50	4.76	5.75	Stopped t=1.4
M700/20	700x425x50	20	8.10	9.28/2.0	Stopped t=4.8
M995/50	995x425x50	50	22.5	29	Stopped t=3.8
M1320/100	1320x425x50	100	7.30	8.5/ -40	t=3.97
M1320/50	1320x425x50	50	19.15	41	t=1.76

s_{ult} Masonry = 18 N/mm^2, t= normal time (Model t=1.0 =15 mins, Prototype t=1.0 = 60 mins)

deflection + towards furnace, - away from furnace.

Table 1. Experimental Testing



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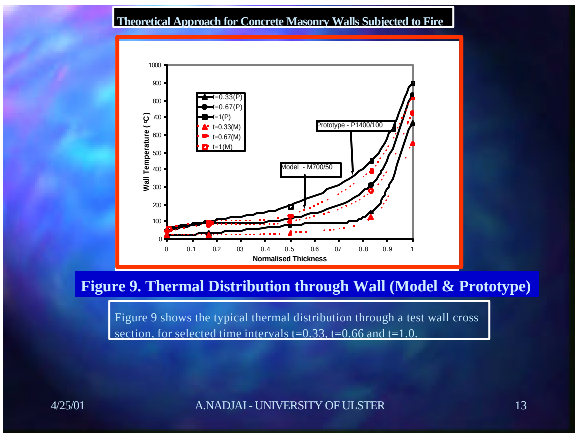
- The curves are presented on a normalised time scale to permit comparison of model and prototype.
- M995/50 exceeded the theoretical curve by 4.7%
- All other model curves fell short of the theoretical curve
- M700/20 2.5%, M1350/50 12.24% and M700/50 13.9%
- Excellent correlation with P1400/100 1%.



Theoretical Approach for Concrete Masonry Walls Subjected to Fire

Figure 9. Thermal Distribution through Wall (Model & Prototype)

Figure 9 shows the typical thermal distribution through a test wall cross section, for selected time intervals t=0.33, t=0.66 and t=1.0.

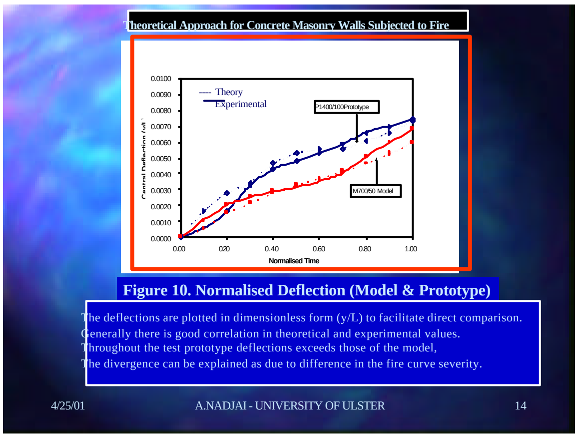


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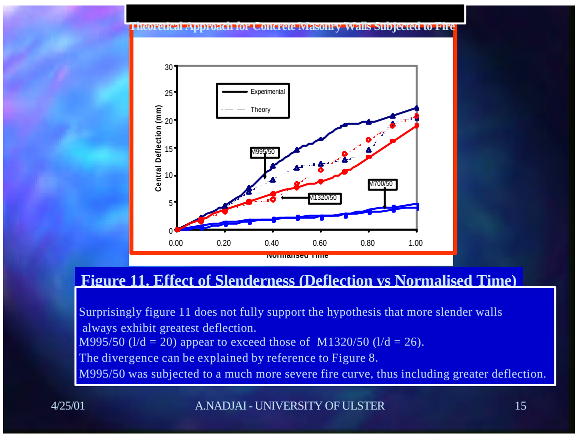
Figure 10. Normalised Deflection (Model & Prototype)

The deflections are plotted in dimensionless form (y/L) to facilitate direct comparison.
Generally there is good correlation in theoretical and experimental values.
Throughout the test prototype deflections exceeds those of the model,
The divergence can be explained as due to difference in the fire curve severity.



Theoretical Approach for Concrete Masonry Walls Subjected to Fire

Figure 11. Effect of Slenderness (Deflection vs Normalised Time)

Surprisingly figure 11 does not fully support the hypothesis that more slender walls always exhibit greatest deflection.
M995/50 (l/d = 20) appear to exceed those of M1320/50 (l/d = 26).
The divergence can be explained by reference to Figure 8.
M995/50 was subjected to a much more severe fire curve, thus including greater deflection.

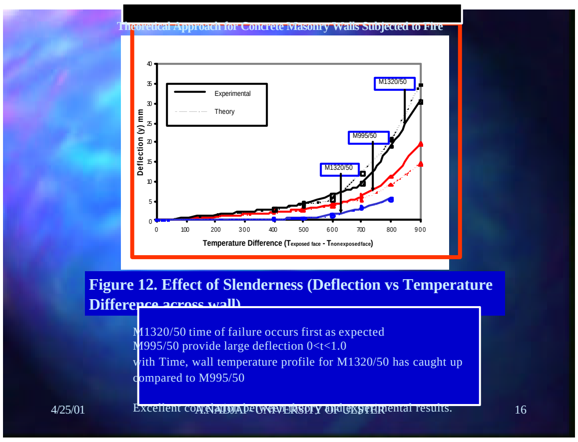


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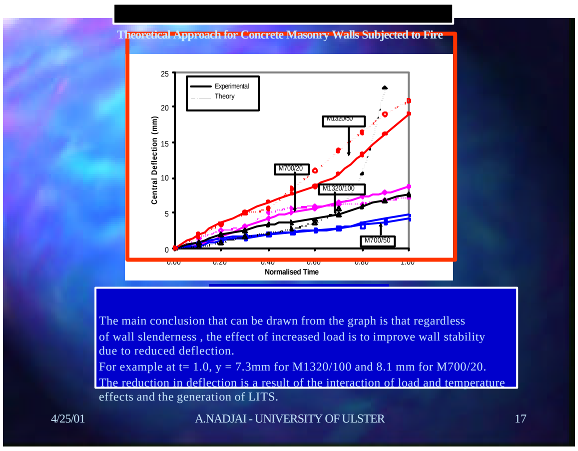
Figure 12. Effect of Slenderness (Deflection vs Temperature Difference across wall)

M1320/50 time of failure occurs first as expected
M995/50 provide large deflection 0<t<1.0
with Time, wall temperature profile for M1320/50 has caught up compared to M995/50

Excellent correlation between theory and experimental results.



Theoretical Approach for Concrete Masonry Walls Subjected to Fire

The main conclusion that can be drawn from the graph is that regardless of wall slenderness , the effect of increased load is to improve wall stability due to reduced deflection.
For example at t= 1.0, y = 7.3mm for M1320/100 and 8.1 mm for M700/20.
The reduction in deflection is a result of the interaction of load and temperature effects and the generation of LITS.

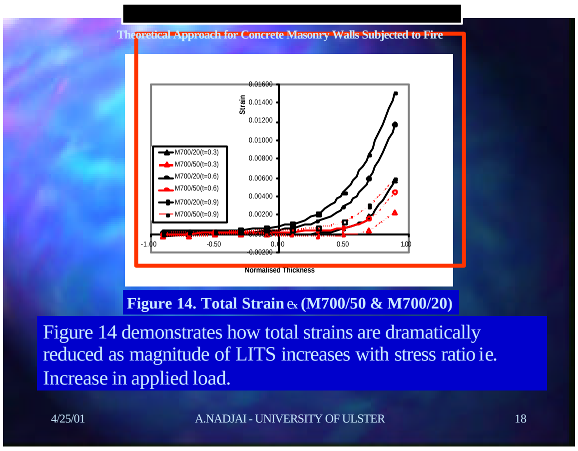


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Figure 14. Total Strain ε_x (M700/50 & M700/20)

Figure 14 demonstrates how total strains are dramatically reduced as magnitude of LITS increases with stress ratio ie. Increase in applied load.

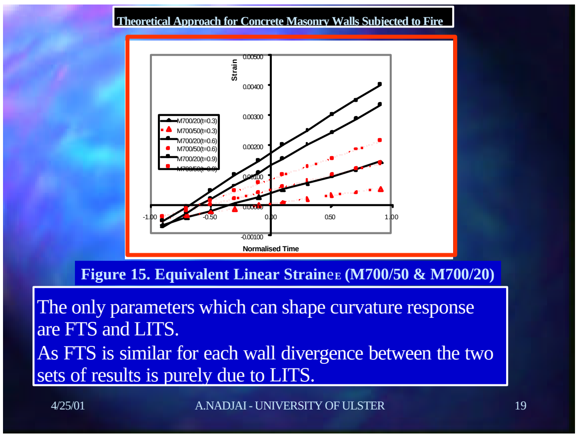

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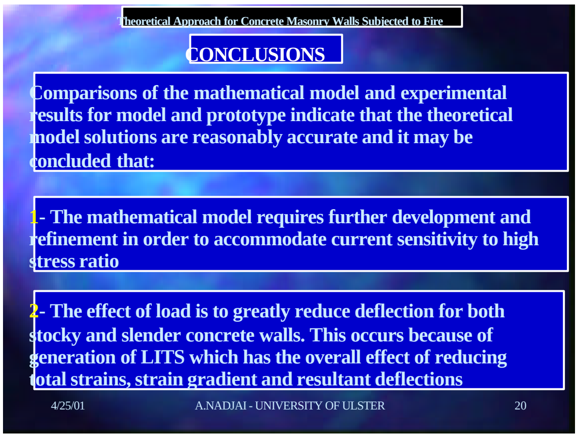
Figure 15. Equivalent Linear Strain ε_E (M700/50 & M700/20)

The only parameters which can shape curvature response are FTS and LITS.

As FTS is similar for each wall divergence between the two sets of results is purely due to LITS.



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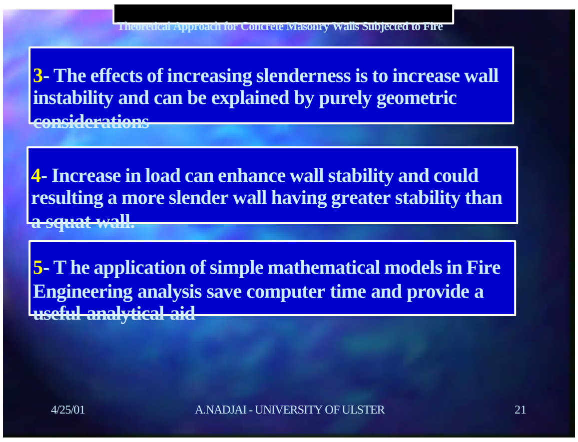
CONCLUSIONS

Comparisons of the mathematical model and experimental results for model and prototype indicate that the theoretical model solutions are reasonably accurate and it may be concluded that:

1- The mathematical model requires further development and refinement in order to accommodate current sensitivity to high stress ratio

2- The effect of load is to greatly reduce deflection for both stocky and slender concrete walls. This occurs because of generation of LITS which has the overall effect of reducing total strains, strain gradient and resultant deflections



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3- The effects of increasing slenderness is to increase wall instability and can be explained by purely geometric considerations

4- Increase in load can enhance wall stability and could resulting a more slender wall having greater stability than a squat wall.

5- T he application of simple mathematical models in Fire Engineering analysis save computer time and provide a useful analytical aid