LAUTECH JOURNAL OF ENGINEERING AND TECHNOLOGY 1(1) 2003: 40-46

ANALYTICAL APPROACH OF EARTH MASONRY INFILL-PANEL SUBJECT TO SEISMIC LOADS

Adedeji A. A.

Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria
E-mail: amadeji@ yahoo.com

ABSTRACT

Earth wall has been observed to be a structural, flexible and inexpensive element in construction. In this work an investigation was carried out on the earth (laterite) wall as an infill panel to determine its hysteric parameters, strength degradation and stiffness decay due to seismic loading. Prediction formulation, for the lateral strength and stiffness parameters of the panel was obtained. Equivalent strut model was found to be appropriate in the analysis, while Bouc-Wen model was employed for hysteresis behaviour. The multistory frame structure with the earth wall in-fills behaves purely as braced element in which the lateral loads are resisted by a truss mechanism, formed by the compression in the earth wall infill panels and tension in the column. The force-displacement response for this element may be employed to assess the overall structural damage and its distribution to a sufficient degree of accuracy.

INTRODUCTION

Laterally braced frames are the stiffened frames, especially when the lateral bracing provides the required stiffness necessary for the frame to resist side sway. The bracing could be provided by the use of concrete (sandcrete) wall, earth wall, burnt brick wall and other masonry materials. Earth wall has been observed to be structurally, and *economically viable element* in construction. A large number of buildings are constructed, in the past and even now, with earth (unburnt bricks) wall and for architectural needs or aesthetic reasons. However, because of the complexity of the problem and absence of a realistic, yet simple analytical model, the function of the earth wall as an infill in the composition with other material is often neglected, especially in the non-linear analysis of structures. For sever earthquakes, for instance, it may not be practicable to design structural elements to remain elastic. The basic for selection of design criteria, repair techniques and construction details were suggested by Florato et al (1970). The simple neglect of non-linear analysis may lead to a substantial inaccuracy in predicting lateral stiffness, strength and durability of the structure. The behaviour of masonry in-filled frames has been studied (Florato et al.1970, Florato et al.1983, Mehrabi et al. 1996, Adedeji, 2001 and Adedeji 2002) in the past four decades in an attempt to develop a rational approach for design of such frames

Engineering formulations are provided for the capacity values corresponding to the studied failure modes for the purposes of design. Saneinejad et al (1995) developed a method based on the equivalent diagonal strut approach for the analysis and design of steel or concrete frames with concrete or masonry infill walls subjected to inplane forces. The method takes into account the elastoplastic behaviour of infilled frames considering the limited ductility of infill materials. Various factors such as the infill aspect ratio, the shear stresses at the infill frame interface, and relative beam and column strengths are accounted for in this development. However, the formulation furnishes only extreme or boundary values for design purposes.

In order to perform a step-by-step force-displacement response analysis of large buildings with earth wall infilled frames, a model for earth wall infill panels is required. Furthermore, for seismic design and evaluation purposes where a complete dynamic time-history analysis may be required, a hysteretic model is necessary.

Analytical Modeling of Earth Wall Infill Panel The analytical development assumes that the contribution of the earth wall infill panel, as shown in Fig. 1a, to the response of the infilled frame can be modeled by "replacing the panel" by a system of two diagonal earth wall compression struts as in Fig.1b. However, the combination of both diagonal struts provides a lateral load resisting mechanism for the opposite lateral directions of loading.

The lateral force-displacement relationship for the structural earth wall infill panel is assumed to be a smooth curve bounded by a bilinear strength envelope with an initial elastic stiffness until the yield force, V, and there on a post yield degraded stiffness until the maximum force, V_m, is reached. The analytical formulation was based on the equivalent strut model for infilled masonry as suggested by Saneinejad et al (1995) and is described briefly as follow:

Equivalent Strut Model

Considering the infilled earth wall frame shown in Fig1a,b, the maximum lateral force, V_m, and corresponding displacement u_m in the infill wall panel are expressed as (Saneinejad et al.1995):

$$V_m'(V_m) = A_d f_m' \cos\theta = \frac{vtL'}{(1-0.45\tan)\cos\theta} \leq \frac{0.83tL'}{\cos\theta} \qquad (1)$$

and,

$$u_m'(u_m) = \frac{\varepsilon_m' L_d}{\cos\theta} \qquad (2)$$

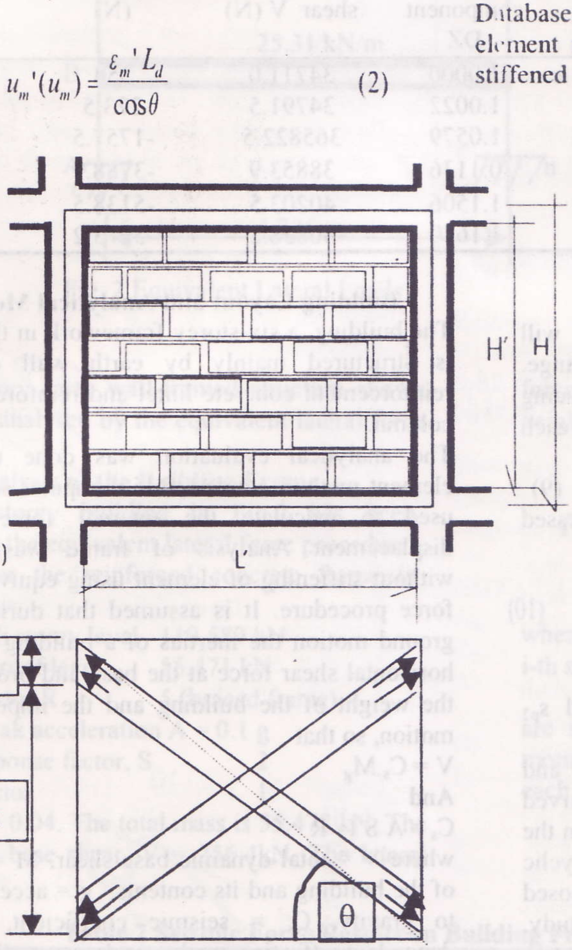


Fig. 1 Wall equivalent diagonal strut

Note: In figure 1 : $d_1 = \alpha_c - H'$ and $d_2 = (1 - \alpha_c)$

Time Independent Smooth Hysteresis Model

A smooth hysteretic model is proposed for the structural earth-wall infill panel. The model, which was developed based on the Bouc- Wen model for hysteresis behaviour (Bouc 1967, Berber et al. 1985) and which furnishes a smooth hysteresis force-displacement relationship between force V and displacement u, where:

In which t= thickness of the infill panel, L' = lateral dimension of the wall panel, f_m' = characteristic strength of earth (brick) wall, ε = corresponding strain, θ = inclination of the diagonal strut, ν = basic shear strength earth wall and A_d, L_d = area and length of the equivalent diagonal struts respectively and calculated as (Saneinejad et al. 1995):

$$A_d = (1-\alpha_c)\alpha_c tH'\frac{\sigma_c}{f_c} + \alpha_b tL'\frac{\tau_b}{f_c} \leq \frac{0.5tH'\frac{f_a}{f_c}}{\cos\theta} \qquad (3)$$

and

$$L_d = ((1 - \alpha_c)_2 h'^2 + L'^2)^{0.5} \qquad (4)$$

Where the quantities α_c, α_b, σ_c, τ_b, f_c, f_d, depending on the geometric and material properties of the frame and infill wall and can be estimated using formulations of the equivalent strut model. From the Database, A_d = 3.364 E-3 m^2 and L_d = 2.353m. Finite element method was use to analyse the framework stiffened with the earth wall.

$$V_i = V_y\,[\alpha\,\mu_i + (1 - \alpha)\,Z_i] \qquad (5)$$

Where μ_i = ductility calculated as μ_i/μ_y and defined, by Moroni et al (1996), in line with the displacement amplification factor according to allowable stress design format; subscript i = instantaneous values, subscript y = yield values, α = post yield stiffness and Z = hysteretic component determined by solving the following differential equation by Reinhorn et al (1985) as:

$dZ_i = \{A - |Z_i|^n [\beta \mathrm{sign}(d\mu_i Z) + \gamma]\} d\mu_i$ (6)

where signum function sgn(x) = -1 for x > 0; A. β and γ = constants that control the shape of the generated hysteretic loops (Assumed values: A = 1, β = γ = 0.5) and n = transitional rate from the elastic to yield state.

Stiffness Decay

The yielding system in general is the loss of stiffness due to deformation beyond yield point. The stiffness decay is incorporated directly in the hysteretic model by including the control parameter η (obtained by pivotal deterioration method (Madan et al. 1997) by solving differential equation) in eqn (6) for hysteric parameter Z.

$dZ_i = \{A - |Z_i|^n [\beta \mathrm{sign}(d\mu_i Z) + \gamma]\} d\mu_i \eta$ (7)

and

$$\eta = \frac{[S_k + \alpha(\mu_i - 1) + 1]}{[S_k + \mu_i]} \qquad (8)$$

in which S_k = multiplier for V_y to define the pivot for stiffness deterioration. A default value for S_k is taken to be 5. Dynamic response characteristics shown in Table 1 showing storey numbers their maximum story shear and decay stiffness. It could be observed that stiffness degradation increases with respect to the height of the building with respect to shear.

Table 1. Dynamic Response Characteristics with Stiffness Decay

No. of floors	Strain δ (mm)	Ductility (μ_1)	Control parameter (η)	Hysteretic component DZ	Max. floor shear V (N)	Shear Decay (N)	Stiffness decay (N/mm)
1	4.44	1.0000	1.0000	1.0000	34711.0	354	159.5
2	4.50	1.0135	0.9978	1.0022	34791.5	273.5	121.6
3	6.00	1.3514	0.9453	1.0579	365822.5	-1757.5	-585.2
4	7.50	1.6892	0.8980	0.1136	38853.9	-3788.9	-1010.4
5	8.50	1.9144	0.8691	1.1506	40203.5	-5138.5	-1209.1
6	8.97	2.0202	0.8562	1.1680	40838.2	-5773.2	-1287.2

Strength Degradation

Degrading system as earth wall infill panels will also exhibit loss of strength in the elastic range. The strength deterioration is modeled by reducing the yield force V from the original value V_{oy} each step K:

$V_k = V_{oy}(1 - DI)$ (9)

As DI = cumulative damage and is expressed as[10]:

$$DI = \frac{\mu_{max} - 1}{\mu_c - 1}\left[1 - 0.25 s_{p1} \int \left(\frac{V}{V}\right) \frac{d\mu}{(\mu_c - 1)}\right] s_{p2} \qquad (10)$$

where μ_c = monotonic ductility, s_{p1} and s_{p2}

Cracking Slope Model

Pinching of hysteresis loops due to opening and closing of masonry cracks is a commonly observed phenomenon in masonry and most especially in the earth wall element (Adedeji 2002) subject to cyclic loading. The concept of slip-lock element proposed by Baber et al (1981) was adopted in this study. This is incorporated in series $\mu = \mu_1 + \mu_2$, with the smooth degrading element and displacement ductility due to the slip-lock element. The advantage of this proposal is that it provides a time rate-independent force-displacement rule for a hysteretic degrading pinching element. This may be implemented for dynamic time-history analysis of structures incorporating earth wall panels.

Building Layout and Analytical Modeling

The building, a six-storey framework in this analysis, is structured mainly by earth wall coupled by reinforcement concrete lintel and reinforced concrete column.

The analytical evaluation was done using finite element method, while QB45 computer software was used to calculate the internal forces and the displacement Analysis of frame was performed without stiffening of element using equivalent lateral force procedure. It is assumed that during a strong ground motion the inertias of a building results in a horizontal shear force at the base and proportional to the weight of the building and the imposed ground motion, so that

$V = C_s M_g$ (11)

And

$C_s = A\,S\,I / R$ (12)

where V = total dynamic base shear. M = total mass of the building and its contents, g = acceleration due to gravity, C_s = seismic coefficient. A site dependent effective peak acceleration. S = seismic response factor, R = factor related to ductility of structure or force reduction factor. R-value diminishes as the wall density increases and I = intensity factor. A good example of the seismic records characteristics is shown by Moroni et al (1996) from 1985 Chilean earthquake.

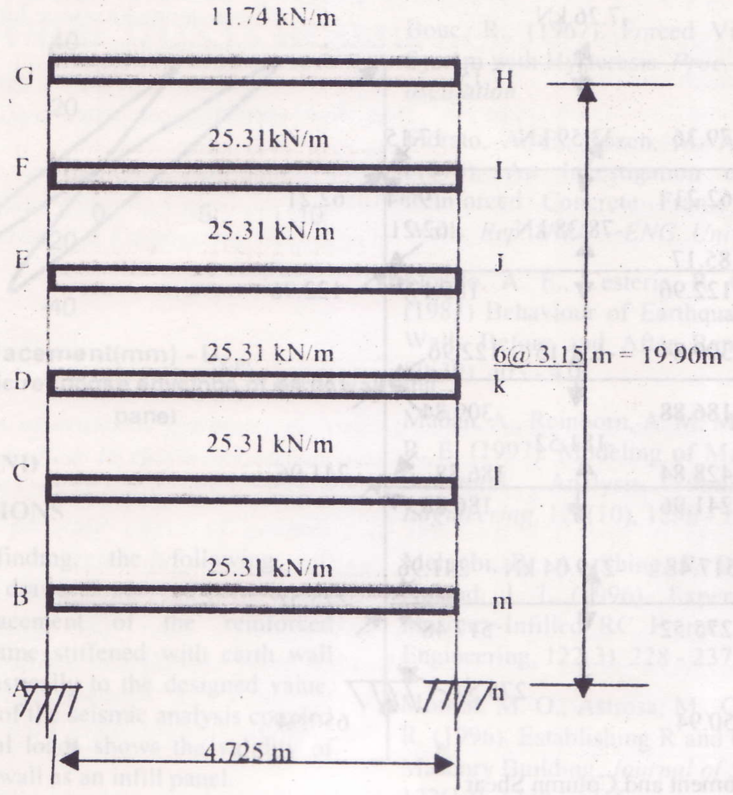


Fig. 2 Equivalent Lateral Loads

The six-storey earth wall-framed structure shown in Fig. 2 is analysed by the equivalent lateral force procedure

Seismic Analysis of the Building Frame

The five storey building in Fig.2 has been analyzed by the equivalent lateral force procedure. Database for the reinforced concrete frame is shown below:

Mass at each storey level	119.589 kN
Mass at the roof level	55.471 kN
Ductility factor R	5 (braced frame)
Effective peak acceleration A = 0.1 g	
Seismic response factor, S	2
Intensity factor	1

So that Cs = 0.04. The total mass is 55.472 kN. The total design base shear, V= 256.4kN. The lateral forces on the building are distributed over the height according ly as:

$$F_i = V\left(\frac{m_i h_i}{\sum_{1}^{n} m_i h_i}\right) \qquad 13$$

where $m_i\ h_i$ = mass and height associated with i-th storey.

The results of the seismic force analysis are shown in Table 2. In Fig. 3 however, moments and column shears are indicated at each level.

Table 2 Seismic Force Results on Building Frame

Store Level	Equivalent lateral force (kN)	Equivalent lateral shear force (kN)
Roof	21.77	21.77
5	57.25	79.02
4	77.08	156.10
3	81.27	237.37
2	69.82	307.19
1	42.73	349.92
Total Dynamic Base Shear		349.92

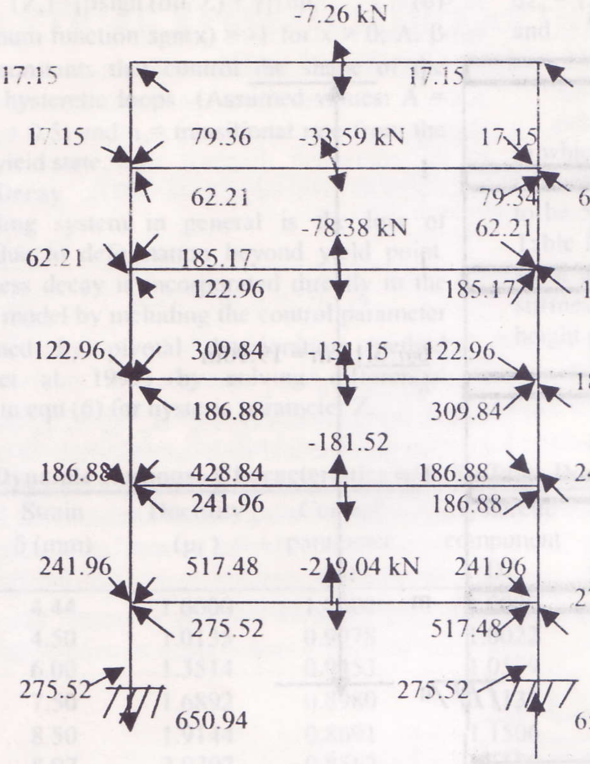
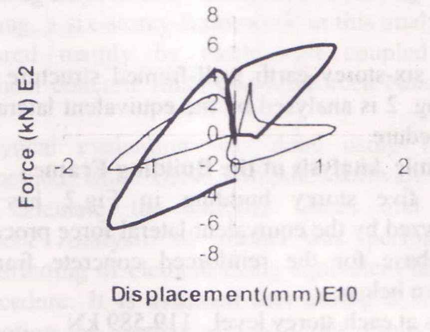


Fig. 3 Moment and Column Shear

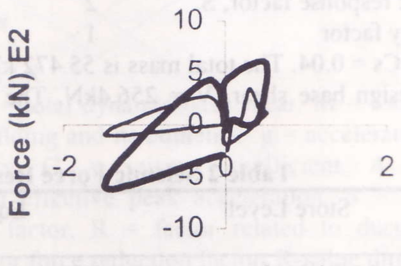
RESULTS AND DISCUSSION

The finite element method of analysis was used in the computation of internal forces and displacements of the stiffened frame with earth wall. In the analysis, the infill panel was assumed to act as a system of two diagonal earth wall compression struts. The combination of the two diagonals provides a lateral load resisting mechanism for the opposite direction of loading. The deflection characteristics of the frame without the infill panel are more pronounced than when stiffened with the earth wall.

The hysteresis loops were generated as a result of the seismic loads. The total increase in the storey shares indicates that the infill earth panel contributed to 90% of the overall stiffness of the structure. Figure 4a and Fig. 4b shows the force-displacement relationships for two loading cases. Typical dynamic response of the earth wall was shown in Fig. 5 as the loops envelope shows constant shear force with varied displacement. The hysteretic energy dissipation was reduced detriment to damage of the structure.



(a) case (I)



(b) Case (II)

Fig. 4: Force Displacement Curve for Stiffness Bare Frame

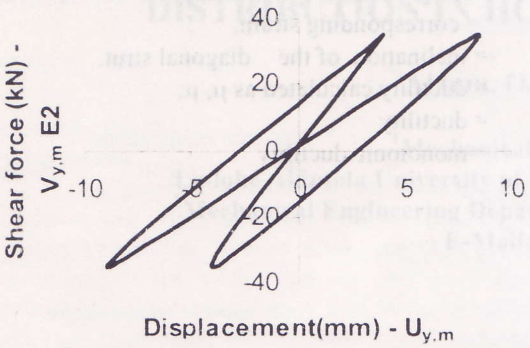


Fig. 5 Dynamic response envelope of earth wall infill panel

CONCLUSIONS AND RECOMMENDATIONS

Based on this finding, the following conclusions were drawn

- The displacement of the reinforced concrete frame stiffened with earth wall reduced drastically to the designed value. The results of the seismic analysis coupled with vertical loads shows the validity of using earth wall as an infill panel.
- The computed force-displacement response may be used to assess the over all structural damage and its distribution for design purposes.
- It is worthwhile to recommend, for future work, that for the analysis where emphasis is on evaluating structural response, macro models can be substituted for micro models without substantial loss in accuracy and with a gain in the computational efficiency.
- In seismic design of infill frame with earth wall, ductility of 5 and above may be required

REFERENCES

Adedeji, A. A. (2001). Analysis of Framed Structures Stiffened with Masonry Infills, *Proj. Submitted to Dept. of Civil Engineering*, University of Ilorin, Nigeria, 1- 15.

Adedeji, A. A. (2002) Assessing and Managing Earth Wall Deterioration and Design, *Nigerian Journall of Engineering Management*, 47 – 51

Berber, T. T. and Noor, M. N. (1985). Random Vibration of Degrading Pinching System, *J. Engineering Mechanics*, ASCE, 111(8), 1010 1026.

Berber, T. T. and Wen, T. K. (1981). Random Vibration of Hysteric Degrading Systems, *Journal of Engineering Mechanics*, ASCE, 107(8), 1069 - 1087.

Bouc, R., (1967). Forced Vibration of Mechanical System with Hysteresis. *Proc. 4th Conf. on non-linear oscillation.*

Florato, A. E., Sozen, M. A. and Gambie, W. L. (1970). An Investigation of the Interaction of Reinforced Concrete Frame with Masonry Filler Walls. *Rep. UILU – ENG. Univ. of Illinois*, 70 – 100.

Florato, A. E., Cesterie, R. G. and Corley, W. G. (1983) Behaviour of Earthquake Resistant Structural Walls Before and After Repair. *ACI Journal*, No. 80(39), 403 - 413.

Madan, A., Reinhorn, A. M. Mander, J. B. and Valles, R. E. (1997). Modeling of Masonry Infill Panels for Structural Analysis, *Journal of Structural Engineering*, 121(10), 1296 - 1302.

Mehrabi, B., A., Shing, P. B., Schuller, M. P. and Noland, J. L. (1996). Experimental Evaluation of Masonry-Infilled RC Frame, Journal of. Structural Engineering, 122(3), 228 - 237.

Moroni, M. O., Astrosa, M., Gumez, J. and Guzman, R. (1996). Establishing R and C Factors for Confined Masonry Building, *Journal of Structural Engineering*, 122(10), 1208 - 1215.

Reinhorn, A. M., Mandan, A. Valles, R. E. Reichman, Y. and Mander, J. B.(1995). Modeling of Masonry Infill Panels for Structural Analysis, Rep. NCEER 95-0018, New York, and NY.

Saneinejad, A. and Hobos, B. (1995). Inelastic Design of Infilled Frames, *Journal of Structural Engineering*, ASCE, 121(4), 634 - 650.

NOTATION

A_d, = area of the equivalent diagonal struts
C_s = seismic coefficient,
A = site dependent effective peak acceleration
DI = cumulative damage
f_m = characteristic strength of earth (brick) wall,
g = acceleration due to gravity,
h_i = mass and height associated with i-th storey
L_d = area and length of the equivalent diagonal struts
L' = lateral dimension of the wall panel,
M = total mass of the building and its contents
n = transitional rate from the elastic to yield state
R = factor related to ductility of structure or force reduction factor.
S = seismic response factor
S_f = multiplier
t = thickness of the infill panel
V = total dynamic base shear

V_y = shear

Z = hysteric component

v = basic shear strength earth wall.

α = post yield stiffness

β = constants that control the shape of the generated hysteric loops

γ = constants that control the shape of the generated hysteric loops

ε = corresponding strain.

θ = inclination of the diagonal strut.

μ_t = ductility calculated as $\mu_t \mu_c$

μ_2 = ductility

μ_c = monotonic ductility