Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VI)

9-1-4

INELASTIC SEISMIC ANALYSIS OF COUPLED SHEAR WALLS USING DUCTILITY DECAY CURVE

Cledwyn THOMAS[1] and Omar CHAALLAL[2]

[1]Department of Civil Engineering, Liverpool University, Liverpool, England.
[2]Department of Civil Engineering, Technical University of Oran, Algeria.

SUMMARY

The energy input, from an earthquake, into a coupled shear wall can be dissipated by using ductile connecting beams. The rotations at the ends of these beams producing plastic deformation. The required degree of ductility is usually achieved by adjusting the moment capacities of the individual beams.

Usually this is a 'trial and error' iteration process, and the ductility decay curve has been introduced to reduce the number of iterations.

The curve was originally developed using the El-Centro record and symmetrical coupled shear walls. This has now been extended to cover other earthquake records and unsymmetrical coupled shear walls.

INTRODUCTION

Non linear analysis of a coupled shear wall, using DRAIN 2D, enables both the elastic and plastic deformations to be calculated. The element used in the analysis is for a reinforced concrete beam with degradeable stiffness. The degradation is itself based on the experimental Takeda hysteresis model.

In coupled shear walls the plastic deformations are confined to the ends of the connecting beams. This is controlled by specifying an allowable ductility factor (μ). Paulay (Ref. 1) and others (Ref. 2-4) have shown that the limit of shear ductility lies in the range

$$4 \leqslant \mu \leqslant 10$$

In this study the ductility that is calculated is the rotational ductility at the ends of the connecting beams. This is defined as

$$\mu = \frac{\theta p + \theta y}{\theta y}$$

where

θp = plastic rotation

θy = rotation at yield of steel

Therefore if moment capacities are assigned to the connecting beams then the rotational ductility can be calculated from the analysis. The moment capacities are then adjusted and the values of ductility recalculated. This procedure is then repeated on a trial and error basis until suitable ductility values are obtained. The ductility decay curve was developed to introduce some logic into the above process. Also the number of iterations required would be reduced.

Development of Ductility Decay Curve

The curve was initially developed using the first three of the coupled shear walls in Fig. 1. The earthquake record used was the first ten seconds of N-S component of the El-Centro earthquake record. The walls were subdivided into zones of five storeys to minimise the computer effort. Inside each zone the moment capacity of all the connecting beams is constant. When the same moment capacity is applied to every zone the variation of the ductility demand is as shown in Table 1(a).

Previous work by Chaallal et al (Ref. 5) has shown that the variation of moment capacity in any zone only affects the ductility demands of that particular zone. The ductility demand decreases as the moment capacity increases, as shown for five walls in Table 1(b). This work was then extended to consider the decrease of moment capacity in a zone and the ductility decay curve shown in Fig. 2 produced.

Berrais (Ref. 6) has recently shown that this curve is applicable to the Parkfield 1972 and El Shellef 1980 earthquake records and also to unsymmetrical shear walls SW6 and SW7 in Fig. 1.

Application of Ductility Decay Curve

The procedure for the coupled shear walls analysed was as follows:

(a) Define required ductility factor (μ_R)

(b) Calculate min^m moment capacities for connecting beams or zones of connecting beams.

(c) Carry out non linear analysis using DRAIN 2D program

(d) Read off the value of plastic rotation and calculate yield rotation

(e) Calculate ductility factor (μo) and ductility ratio ($\frac{\mu r}{\mu o}$)

(f) Using ductility decay curve read off value of ($\frac{dm}{M}$)

(g) Recalculate moment capacities M = M + dM

(h) Repeat procedure from (c) above until ductility factors sufficiently close to required values.

EXAMPLES

(a) <u>El-Centro N-S earthquake record</u>

Walls SW1, SW2 and SW3 were subjected to the first ten seconds of El-Centro earthquake NS component. As can be seen from Table 2, both SW1 and SW3 attain the required ductility in one iteration. The ductilities for wall SW2 are not close to the required ductility but a further two iterations as shown in Table 3 produce the required ductility values.

(b) <u>Taft earthquake record</u>

The walls SW1 and SW2 were subdivided into zones of two storeys. It was found that zones of five storeys did not produce reasonable convergence of the ductility values. Wall SW1 required four iterations as can be seen from Table 4, but wall SW1 only required two iterations as shown in Table 5.

(c) <u>Parkfield earthquake record</u>

Wall SW6 was analysed for this earthquake record for a required ductility factor of 4. Again, zones of two storeys were used and the required ductility values were obtained in three iterations.

(d) <u>El Shellef earthquake record</u>

The required ductility factor for wall SW7 with this earthquake record was 4. As can be seen from Table 7 this required value was achieved in four iterations.

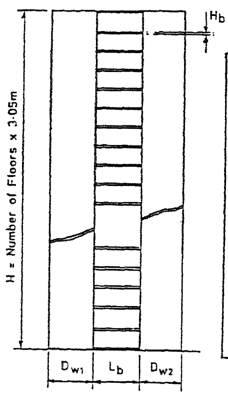
CONCLUSIONS

The results above show that the ductility decay curve works effectively for various wall geometries. The basic assumption is that moment plastic deformation takes place. With short deep beams the probability is that shear plastic deformation will take place. At present research is being carried out to provide a reasonable model for this type of deformation.

REFERENCES

1. Paulay, T., Santkumar, A.R. "Ductile Behaviour of Coupled Shear Walls," Jnl. Str. Div., A.S.C.E., Vol. 102, No. STI, Jan. 1976, pp. 93-108.
2. Beretero, V.V., "Seismic Behaviour of R/C Wall Structure Systems,"Proceedings 7th World Conference on Earthquake Eng., Vol. 6, Turkey, (1980).

3. Fintel, M., Ghosh, S.K., "Design of Walled Structures for Earthquake Loading," Non-Linear Design of Concrete Structures, C.S.C.E., A.S.C.E., ACI, CEB, International Symposium, Canada, Aug. 7-9, 1979.
4. Fintel, M., Ghosh, S.K., "Explicit Inelastic Dynamic Procedure for Aseismic Structures,", ACI Journal, Vol. 79, March, April, 1982, pp. 110-118.
5. Chaallal, O., Thomas, C., "The Use of Ductility Decay Curve in the Analysis of Coupled Shear Walls," Proceedings 8th European Conference on Earthquake Eng., Lisbon 1986, Vol. 3 p. 6.5/9.
6. Berrais, A., MSc(Eng) 1988 thesis, Civil Engineering Dept., University of Liverpool, England.



	SW1	SW2	SW3	SW6	SW7
D_{w1} (m)	3·66	3·66	3·66	3·66	3·66
D_{w2} (m)	3·66	3·66	3·66	2·44	1·22
H (m)	61·00	91·44	30·48	0·61	0·61
L_b (m)	2·13	2·13	2·13	2·13	4·26
H_b (m)	0·61	0·61	0·61	0·61	0·61
H_f (m)	3·05	3·05	3·05	3·05	3·05
Fundamental Period (sec.)	1·85	3·78	0·55	1·00	1·70

FIG. 1. GEOMETRIC AND DYNAMIC PROPERTIES OF THE COUPLED SHEAR WALLS

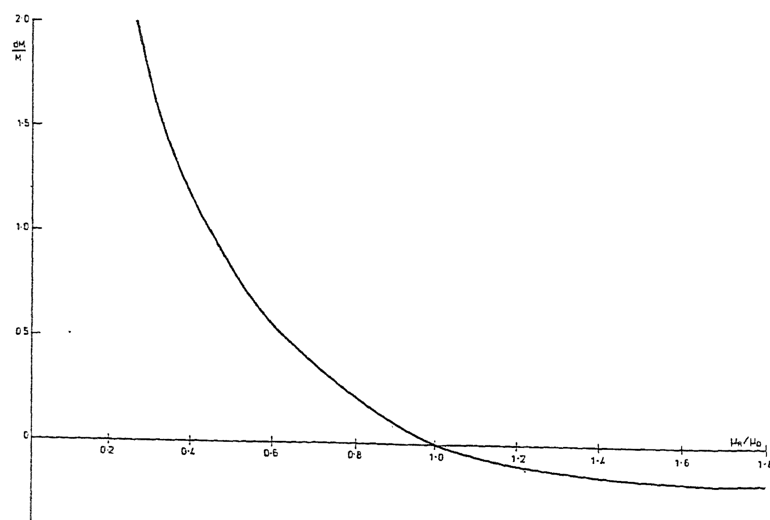


FIG. 2. DUCTILITY DECAY CURVE

	DUCTILITY DEMAND AT My_{MIN}				
ZONE	SW1	SW2	SW3	SW4	SW5
1	13·51	6·48	9·95	9·36	8·02
2	17·43	8·32	12·51	12·14	10·54
3	22·24	12·79	13·64	11·93	13·46
4	22·77	14·67		14·73	13·38
5		14·06		17·69	16·94
6		16·06		18·03	18·16

TABLE 1(a)

	DUCTILITY DECAY $\left(\frac{\mu_R}{\mu_o}\right)$				
$\frac{dM}{My_{MIN}}$	SW1	SW2	SW3	SW4	SW5
0·5	0·61	0·61	0·64	0·62	0·61
1·0	0·42	0·40	0·46	0·43	0·42
1·5	0·32	0·28		0·32	0·31
2·0	0·25		0·29	0·25	0·24
3·0	0·18	0·12	0·23	0·17	0·18

TABLE 1(b)

SW1 $\mu_R = 6$ $My_{MIN} = 136kNm$ 4 ZONES

ZONE	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	dM	My	μ_o COMPUTED
1	13·51	0·44	0·98	133	269	5·9
2	17·43	0·34	1·35	184	320	5·5
3	22·24	0·27	1·72	234	370	5·7
4	22·77	0·26	1·74	237	373	5·7

SW2 $\mu_R = 4$ $My_{MIN} = 136kNm$ 6 ZONES

ZONE	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	dM	My	μ_o COMPUTED
1	6·48	0·62	0·50	68	204	3·95
2	8·32	0·48	0·79	107	243	3·83
3	12·79	0·31	1·34	182	318	3·17
4	14·67	0·27	1·53	208	344	3·10
5	14·06	0·28	1·48	201	337	2·86
6	16·47	0·24	1·66	226	362	2·92

SW3 $\mu_R = 6$ $My_{MIN} = 136kNm$ 3 ZONES

ZONE	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	dM	My	μ_o COMPUTED
1	9·95	0·60	0·60	82	218	5·88
2	12·51	0·48	0·93	126	262	5·66
3	13·64	0·44	1·08	147	283	5·55

TABLE 2

SW2 $\mu_R = 4$ $My_{MIN} = 136$ 6 ZONES

ZONE	μ_o COMPUTED	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	My	μ_o COMPUTED	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	My	μ_o COMPUTED
1	3·95	1·01	- 0·01	202	3·80	1·05	- 0·04	194	3·92
2	3·83	1·04	- 0·03	236	3·78	1·06	- 0·05	224	3·94
3	3·17	1·26	- 0·12	280	3·49	1·15	- 0·08	258	3·73
4	3·10	1·29	- 0·13	299	3·48	1·15	- 0·08	275	3·84
5	2·86	1·40	- 0·15	286	2·68	1·49	- 0·16	240	3·50
6	2·92	1·37	- 0·14	311	2·86	1·40	- 0·14	267	3·54

TABLE 3

SW1 $\mu_R = 5$ $My_{MIN} = 68kNm$ 10 ZONES

ZONE	μ_R	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	M	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	M	μ_o	M	μ_o
1	7·01	0·71	0·34	91·1	4·93	1·01	-0·02	89·4	5·05	90·3	4·90
2	11·19	0·45	1·00	36·0	4·89	1·02	-0·02	133·3	5·08	134·6	5·01
3	12·68	0·39	1·22	151·0	4·61	1·08	-0·06	141·8	5·05	143·2	5·02
4	12·63	0·40	1·19	148·9	4·31	1·16	-0·09	135·5	5·04	136·8	4·70
5	11·79	0·42	1·09	142·1	3·65	1·37	-0·15	120·8	4·83	117·1	5·13
6	11·19	0·45	1·00	136·0	3·30	1·52	-0·16	114·2	4·67	108·5	5·12
7	13·91	0·39	1·22	151·0	2·89	1·73	-0·18	123·8	4·64	116·3	5·40
8	16·74	0·30	1·72	185·0	2·63	1·90	-0·18	151·6	4·31	139·5	5·13
9	18·23	0·27	2·00	204·0	2·54	1·97	-0·18	167·3	4·16	148·9	5·16
0	18·45	0·27	2·00	204·0	2·61	1·99	-0·18	167·3	4·16	148·9	5·12

TABLE 4

SW2 $\mu_R = 5$ My_{MIN} = 68kNm 15 ZONES

ZONE	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	M	μ_o	$\frac{\mu_R}{\mu_o}$	$\frac{dM}{M}$	M	μ_o
1	6.7	0.75	0.30	88.4	3.99	1.25	-0.12	77.8	4.78
2	10.9	0.46	0.95	132.6	4.09	1.22	-0.11	118.0	4.82
3	13.0	0.39	1.23	151.6	3.97	1.26	-0.13	131.9	4.39
4	13.2	0.38	1.28	155.0	4.00	1.25	-0.12	136.4	4.71
5	12.4	0.40	1.18	148.2	4.27	1.17	-0.10	133.4	4.69
6	10.2	0.49	0.85	125.8	4.73	1.06	-0.04	120.8	4.91
7	7.6	0.66	0.44	97.9	4.90	1.02	-0.002	97.9	4.88
8	7.3	0.69	0.38	93.8	3.10	1.61	-0.17	77.9	4.63
9	8.2	0.61	0.54	104.7	2.88	1.74	-0.18	85.7	4.62
10	8.6	0.58	0.61	109.5	2.71	1.85	-0.18	89.7	4.46
11	9.3	0.54	0.71	116.3	2.76	1.81	-0.18	95.3	4.59
12	10.6	0.47	0.91	129.9	3.23	1.55	-0.17	107.8	4.95
13	12.5	0.40	1.18	148.2	3.35	1.49	-0.16	124.6	5.03
14	13.4	0.37	1.33	158.4	3.24	1.54	-0.17	131.5	4.99
15	13.5	0.37	1.33	158.4	3.20	1.56	-0.17	131.5	4.97

TABLE 5

$\mu_r = 4$ (1) (2) (3)

FLOORS NUMBER	My min (kN-m)	μ_o	$\frac{\mu_r}{\mu_o}$	$\frac{dM}{My\ min}$	My kN-m	μ comp	My (kN-m)	μ comp
1	90.00	10.94	0.37	1.36	253.00	3.61	311.00	3.27
2	90.00	16.67	0.24	2.25	253.00	6.43	311.00	4.81
3	134.00	15.68	0.26	2.12	445.62	4.68	546.00	3.51
4	134.00	18.92	0.21	2.53	445.62	5.34	546.00	4.04
5	142.60	19.81	0.20	2.63	524.40	4.74	609.00	3.83
6	142.60	20.71	0.19	2.73	524.40	4.71	609.00	3.85
7	136.00	22.42	0.18	2.89	526.90	4.44	552.00	4.11
8	136.00	22.04	0.18	2.86	526.90	4.02	552.00	3.81
9	116.60	24.52	0.16	3.08	469.32	4.01	448.00	4.26
10	116.60	23.32	0.17	2.97	469.32	3.44	448.00	3.74
11	108.00	28.21	0.14	3.35	482.00	2.96	422.00	3.83
12	108.00	31.75	0.13	3.57	482.00	3.43	422.00	4.53
13	115.80	32.69	0.12	3.63	543.70	3.35	492.30	4.35
14	115.80	35.43	0.11	3.76	543.70	3.50	492.30	4.70
15	139.00	31.33	0.13	3.55	637.02	3.01	540.40	4.45
16	139.00	32.55	0.12	3.62	637.02	2.96	540.40	4.51
17	148.30	31.43	0.13	3.56	677.87	2.67	569.80	4.26
18	148.30	32.01	0.12	3.59	677.87	2.53	569.80	4.23
19	148.30	32.22	0.12	3.60	681.67	2.37	591.32	3.93
20	148.30	32.13	0.12	3.60	681.67	2.25	591.32	3.83

TABLE 6

$\mu_r = 4$ (1) (2) (3) (4)

FLOORS NUMBER	My (kN-m)	μ_o	$\frac{\mu_r}{\mu_o}$	$\frac{dM}{My}$	My kN-m	μ comp	$\frac{\mu_r}{\mu_o}$	M kN-m	μ comp	My kN-m	μ comp
1	90.00	1.00	4.00	-0.18	73.80	1.00	4.00	61.26	1.50	52.81	3.25
2	90.00	1.81	2.21	-0.18	73.80	2.54	1.57	61.26	3.42	52.81	4.24
3	134.00	1.35	2.96	-0.18	109.88	2.00	2.00	90.90	2.78	78.40	3.49
4	134.00	1.67	2.40	-0.18	109.88	2.40	1.67	90.90	3.29	78.40	4.10
5	142.60	1.61	2.49	-0.18	116.93	2.34	1.71	98.05	3.19	86.75	3.86
6	142.60	1.71	2.34	-0.18	116.93	2.50	1.60	98.05	3.40	86.75	4.11
7	136.00	1.86	2.15	-0.18	111.52	2.72	1.47	93.80	3.67	87.58	4.09
8	136.00	1.75	2.28	-0.18	111.52	2.59	1.54	93.80	3.52	87.58	3.92
9	116.00	2.79	1.44	-0.159	102.50	3.32	1.21	96.81	3.82	101.02	3.62
10	116.60	3.50	1.14	-0.083	102.50	4.00	1.00	96.81	4.54	101.02	4.26
11	108.00	4.47	0.90	0.098	123.45	3.54	1.13	116.40	4.01	119.29	3.84
12	108.00	4.84	0.83	0.188	123.45	3.76	1.06	116.40	4.25	119.29	4.04
13	115.80	4.92	0.81	0.205	149.02	3.11	1.29	132.80	3.93	138.43	3.63
14	115.80	5.66	0.71	0.368	149.02	3.53	1.13	132.80	4.45	138.43	4.11
15	139.00	4.94	0.81	0.211	173.75	3.10	1.29	151.23	4.11	158.24	3.74
16	139.00	5.28	0.76	0.289	173.75	3.28	1.22	151.23	4.36	158.24	3.95
17	148.30	5.17	0.77	0.263	190.46	3.03	1.32	163.02	4.36	158.24	3.78
18	148.30	5.36	0.75	0.305	190.46	3.11	1.28	163.02	4.28	169.91	3.89
19	148.30	5.43	0.74	0.320	195.65	3.02	1.32	166.30	4.23	172.93	3.83
20	148.30	5.42	0.74	0.318	195.65	2.99	1.34	166.30	4.20	172.93	3.81

TABLE 7