FIFTH SHORT COURSE
SOIL DYNAMICS IN ENGINEERING PRACTICE
WHEELING, IL, APRIL 29-30, 2013

PERFORMANCE BASED SEISMIC DESIGN OF RIGID RETAINING WALLS (WITH DESIGN CHARTS)

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(updated March 2013)

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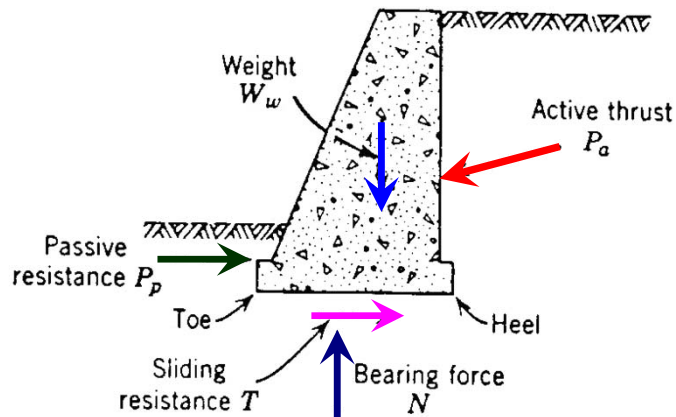**S&T**
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TOPICS

- **STATIC AND DYNAMIC EARTH PRESSURE**
  - **COULOMB AND MONONOBE-OKABE THEORY**

- **DESIGN OF RETAINING WALLS**
  - **PSEUDO STATIC**
  - **DISPLACEMENT BASED**

- **DESIGN PROCEDURE**

- **DESIGN CHARTS**

- **INTRODUCTION TO ABUTMENT BEHAVIOR**

- **RETROFIT OF RETAINING STRUCTURE**

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Forces acting on gravity retaining wall

Weight W_w

Active thrust P_a

Passive resistance P_p

Toe

Heel

Sliding resistance T

Bearing force N

DESIGN CONSIDERATIONS

1. HORIZONTAL SLIDING   ($\geq$1.5)

2. OVERTURING   ($\geq$1.5)

3. BEARING CAPACITY   ($\geq$2.5)

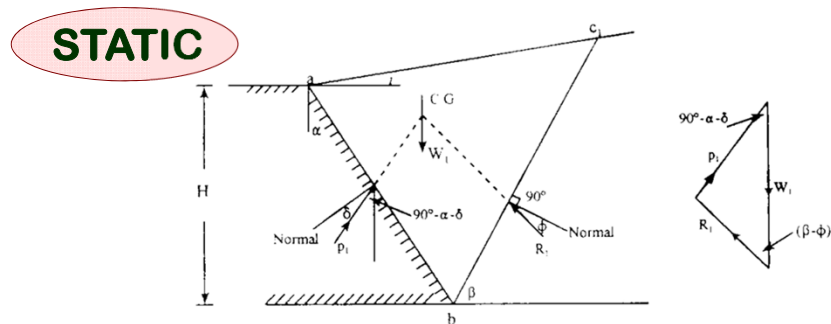**4. ECCENTRICITY OF LOAD ON THE BASE**   ($\leq$B/6)

QUESTIONS TO BE ADDRESSED

1. **EARTH PRESSURE (STATIC AND DYNAMIC)**

2. **POINT OF APPLICATION**

3. **F.S AGAINST SLIDING, OVERTURING AND BEARING CAPAPCITY FAILURE**

4. **DISPLACEMENTS**

5. **DISPLACEMENTS COMPUTATION**

6. **DISPLACEMENTS BASED DESIGN**

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COULOMB'S THEORY

STATIC

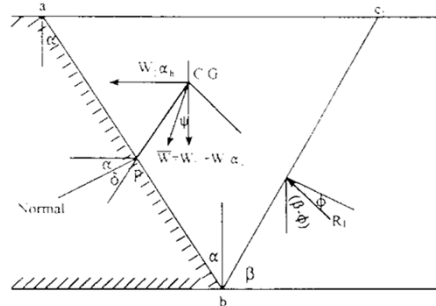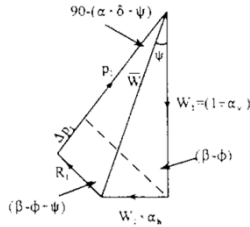Coulomb's analytical expression for **active** earth pressure:

$$P_a = \frac{1}{2}\gamma H^2 \frac{\cos^2(\phi - \alpha)}{\cos^2\alpha \cdot \cos(\delta + \alpha)\left\{1 + \sqrt{\dfrac{\sin(\phi + \delta)\cdot\sin(\phi - i)}{\cos(\alpha - i)\cdot\cos(\delta + \alpha)}}\right\}^2}$$

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MODIFIED COULOMB'S THEORY

DYNAMIC

$$p_{total} = \frac{1}{2}\gamma H^2 \frac{\cos^2(\phi-\psi-\alpha)(1\pm\alpha_v)}{\cos\psi\cos^2\alpha\cos(\delta+\alpha+\psi)} \cdot \frac{1}{\left\{1+\left[\dfrac{\sin(\phi+\delta)\sin(\phi-i-\psi)}{\cos(\alpha-i)\cos(\delta+\alpha+\psi)}\right]^{\frac{1}{2}}\right\}^2}$$

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$$p_{total} = \frac{1}{2}\gamma H^2 \frac{\cos^2(\phi-\psi-\alpha)(1\pm\alpha_v)}{\cos\psi\cos^2\alpha\cos(\delta+\alpha+\psi)} \cdot \frac{1}{\left\{1+\left[\dfrac{\sin(\phi+\delta)\sin(\phi-i-\psi)}{\cos(\alpha-i)\cos(\delta+\alpha+\psi)}\right]^{\frac{1}{2}}\right\}^2}$$

Limitation: for i=0, Ψ>Φ $\quad\Rightarrow\quad \left[\dfrac{\sin(\phi+\delta)\sin(\phi-\psi)}{\cos(\alpha)\cos(\delta+\alpha+\psi)}\right]^{\frac{1}{2}}$ **is imaginary**

In reality: β<0 $\quad\Rightarrow\quad$ A solution is **not possible**

Typical calculation

$\phi=30^0$	$\alpha_v=0$
α_h	$\psi=\sin^{-1}\alpha_h$
0.1	5.74⁰
0.2	11.54⁰
0.3	17.46⁰
	17.46⁰
0.4	23.58⁰
0.5	30⁰
0.515	31⁰

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Mononobe-Okabe method

Retaining wall

Backfill soil

Failure plane (or zone)

Force polygon for soil wedge

$\theta = \tan^{-1}\left[\dfrac{k_h}{1-k_v}\right]$

$P_a = (1/2) \times \gamma \times (K_a) \times H^2$

$P_a = \frac{1}{2}\gamma K_a H^2$

$\phi = 30^\circ$
$\delta = 2/3\phi$
$\beta = \psi = 0^\circ$
$k_v = 0$

Active earth pressure coefficient, K_a

Angle of failure plane, r_v

Applicable limit

Unrealistic large L

Horizontal seismic coefficient, k_h
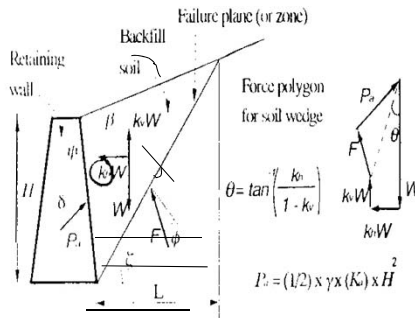
Not applicable at high seismic level

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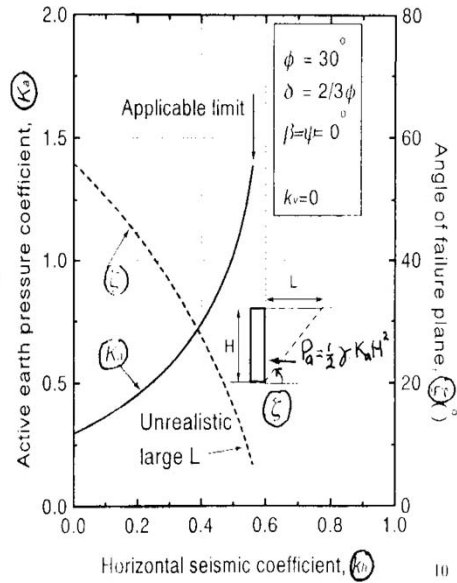
3 EARTHQUAKES RECORDS

SEISMIC COEFFICIENT ?

Acceleration, g

El-Centro Earthquake (M7.1), May 18, 1940, S00E Component

-0.841g

Time, sec

Acceleration, g

0.344g

NorthRidge Earthquake (M6.7), Jan 17, 1994, 90° Component

Time, sec

Acceleration, g

Loma Prieta Earthquake (M7.0), Oct 17, 1989, Diamond Heights

-0.113g

Time, sec

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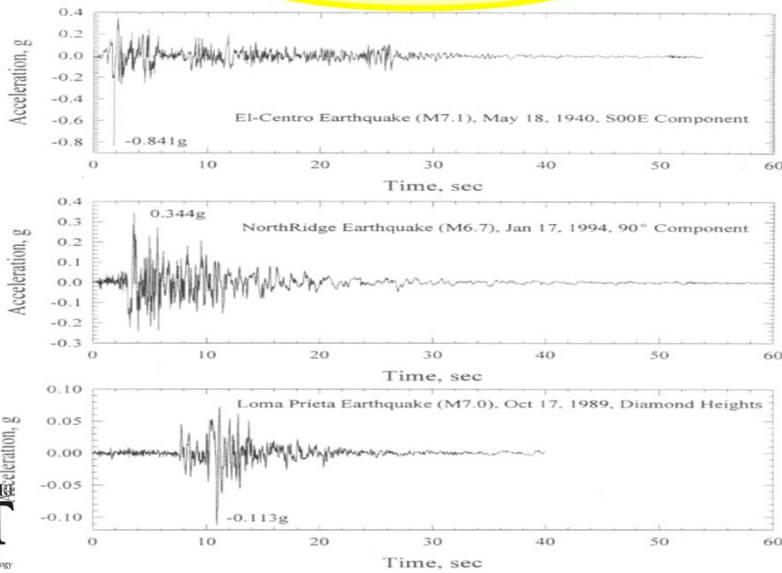
El – Centro earthquake of May18, 1940, SE component (M7.1):

a) accelerogram, b) Fourier's spectrum with predominant frequency.

El-Centro Earthquake (M 7.1), May 18, 1940, S00E Component
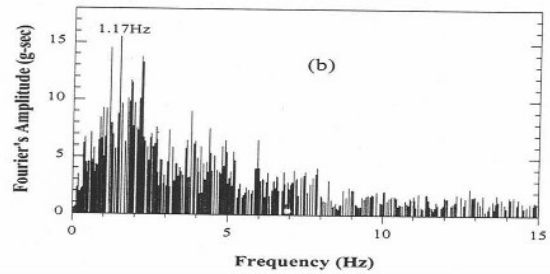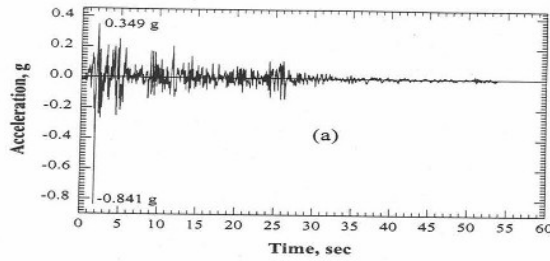
Northridge Earthquake (M 6.7) of Jan 17, 1994, 90• •Component, El Centro
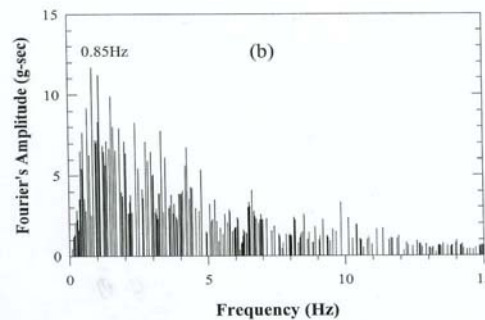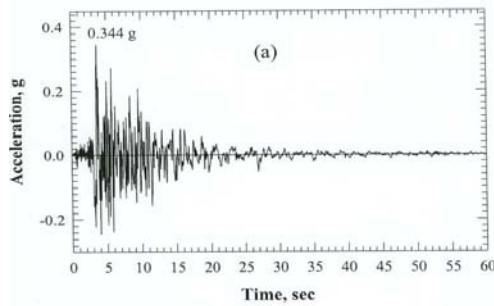
Loma – Prieta Earthquake (M 7.0), Oct. 17, 1989, Diamond Heights (M7.0):

a) accelerogram, b) Fourier's spectrum with predominant frequency.

Loma-Prieta Earthquake (M 7.0), Oct. 17, 1989, Diamond Heights
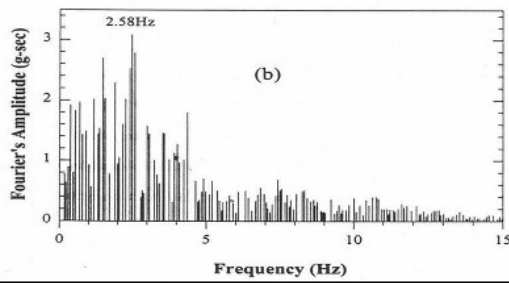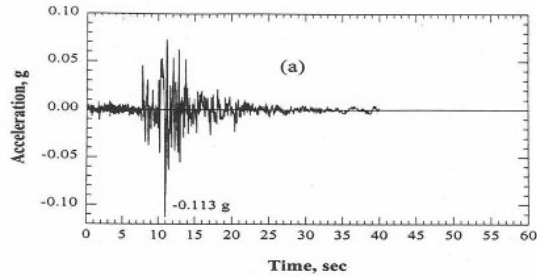
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POINT OF APPLICATION
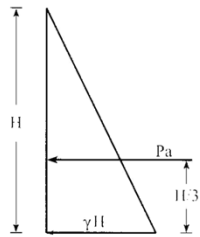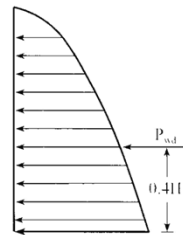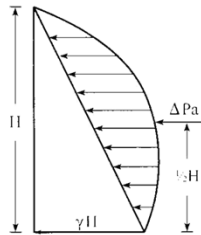
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Static and dynamic earth pressure distribution

⟹ **Behind *1 m* high flexible wall test no. 4**

Pressure, g/cm²

● Dynamic
○ Static

Static ○

Dynamic

Depth, cm

K_a (0.217)

K_0 (0.357)
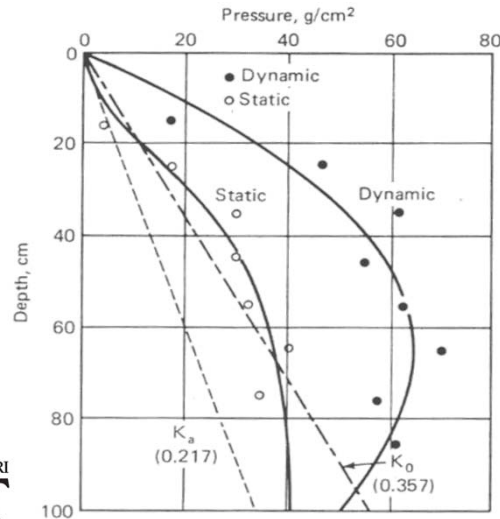
(After Nandkumaran, 1973)

INDIAN CODE FOR ASEISMIC DESIGN OF RIGID RETAINING WALLS

1. Using **Pseudo – Static** approach to evaluate stability of retaining walls

2. Using **Mononobe – Okabe** equation to estimate dynamic earth pressure

3. The point of application of the dynamic increment shall be assumed to be at mid – height of the wall

4. Effect of dry, partially submerged and saturated backfill is considered

5. Range of permissible displacement is not specified

FACTORS OF SAFETY FOR
STATIC DESIGN

- **Sliding** $\geq$ **1.5**

- **Overturning** $\geq$ **1.5**

- **Bearing Capacity** $\geq$ **2.5**

- **Eccentricity** $\leq$ **B/6**

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Seismic coefficients : $\alpha_h = 0.1g$ *and* $\alpha_v = \pm 0.05g$

Case 1

Back fill:
$C = 0$
$\phi = 30°$
$\delta = 20°$
$\gamma = 1.8 \, g/cm^3$

8 m   10°

Case 2

$C = 0$
$\phi = 30°$
$\delta = 20°$
$\gamma = 1.8 \, g/cm^3$

8 m   10°
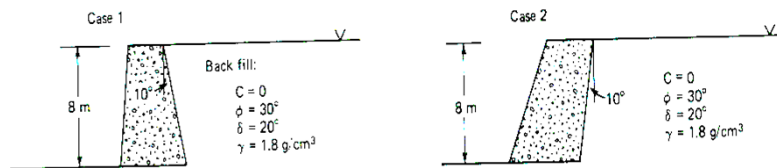
Active Coulomb pressure P_a, T/m of the wall

Case 1			Case 2		
Static	$\alpha_h = 0.1g$ $\alpha_v = +0.05g$	$\alpha_h = 0.1g$ $\alpha_v = -0.05g$	Static	$\alpha_h = 0.1g$ $\alpha_v = +0.05g$	$\alpha_h = 0.1g$ $\alpha_v = -0.05g$
21.52	26.8	25.040	13.440	18.640	17.200
	$\Delta p_{dyn} = 5.28$	$\Delta p_{dyn} = 3.52$		$\Delta p_{dyn} = 5.200$	$\Delta p_{dyn} = 3.760$

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CANTILEVER TYPE WALLS IN KOBE EARTHQUAKE
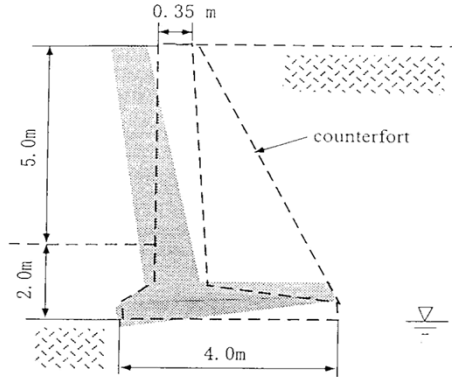
Cantilever retaining walls were constructed 66 years ago. These walls were significantly tilted. The sections without counter fronts suffered cracking at the mid – height of wall.

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BEHAVIOR IN FIELD

Behavior of wing walls during the 1981 earthquake in Greece
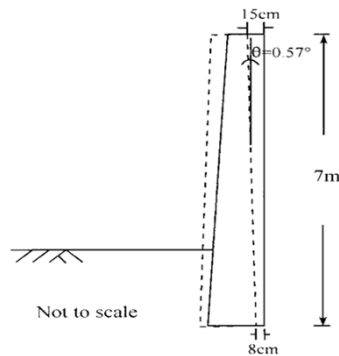
Observed sliding and rocking displacement:

Displacement at base	**= 8 cm**
Displacement at top	**= 15 cm**
Rotation	**= 0.57⁰**

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RICHARD'S AND ELM'S METHOD

1. **Newmark's sliding block analysis (1965) and Franklin and Chang's (1977) solution for upper bound permanent displacements for several natural and synthetic ground motions.**

2. **This approach determines the wall dimensions based on *permissible displacement.***

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NEWMARK'S CONCEPTS

$N \tan\phi$

$FOS = \dfrac{W \cos i \times \tan \phi}{W \sin i}$

$= \dfrac{\tan \phi}{\tan i}$

$\tau = W \sin i$

$N = W \cos i$

W

i

(a)

N'

$(N\text{-}N') \tan\phi$

$W \times \alpha_{cr}$

$\alpha_{cr} = \tan(\phi\text{-}i)$

$FOS = \dfrac{(N\text{-}N') \tan\phi}{(\tau + \tau')}$

$= 1$

$N = W \cos i$

W

i

α_{cr}

$$\alpha_{cr} = \tan(\phi - i)$$

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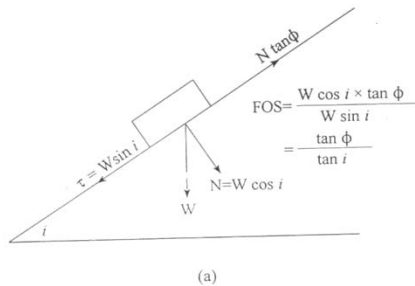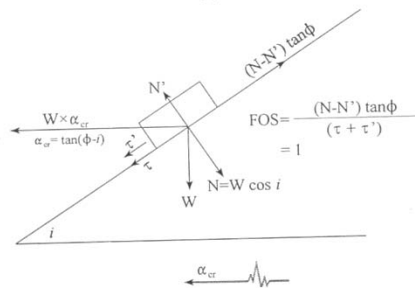
RICHARD'S AND ELM'S METHOD

1. Select a permissible displacement (d).

2. Determine A_a and A_v for a given seismic zone (Applied Technology Council, 1978)

3. Determine coefficient of cutoff acceleration $\alpha_h = \alpha_{cr}$

$$\alpha_h = A_a \left[\frac{0.2 A_v^2}{A_a d} \right]^{0.25}$$

where d is the permissible displacement.
A_a and A_v are acceleration - coefficients in Applied Technology Council (ATC, 1978)

4. Compute dynamic active lateral earth pressure behind the wall using Mononobe – Okabe method for α_h computed in (3) above.

5. Compute weight of wall by using inertia force of the wall and considering force equilibrium.

6. Apply a factor of safety to the calculated weight. A value of 1.5 is recommended and wall dimensions are then determined.

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PERMANENT DISPLACEMENTS FROM NEWMARK'S METHOD

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EXAMPLE

H = 6 m P_{total}

$\alpha_v = 0$
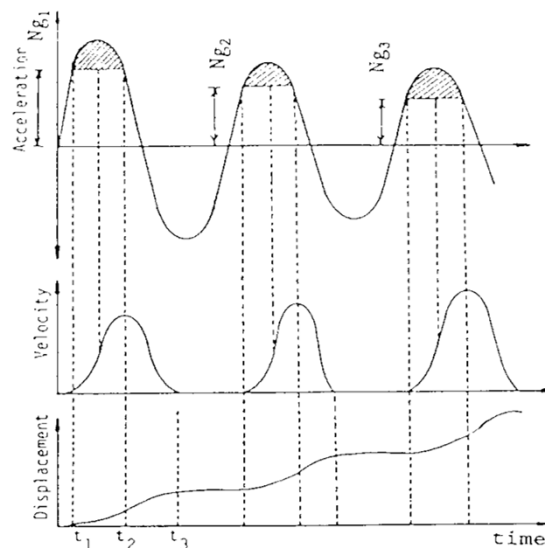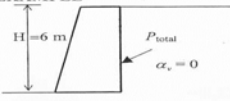
Soil Parameter
$c = 0$
$\phi = 34^o$
$\delta = \frac{1}{2}\phi$
$\gamma = 17.3\ kN/m^3$
$\alpha = 0^o$
$\iota = 0^o$

Richard and Elm's Method

1. Select a permissible displacement $\delta = 100$ mm (4 inch)

2. Determine A_a and A_v for a given seismic zone ATC 3-78,
   $A_v = 0.3$ and $A_a = 0.3$

3. Determine coefficient of cutoff acceleration $\alpha_h = \alpha_{er}$

$$\alpha_h = A_a\left[\frac{0.2\,Av^2}{A_a.d}\right]^{\frac{1}{4}} = 0.3\left[\frac{0.2\times0.3^2}{0.3\times4}\right]^{\frac{1}{4}} = 0.105$$

$$\psi = \tan^{-1}\left[\frac{\alpha_h}{1-\alpha_v}\right] = \left[\frac{0.105}{1-0}\right] = 6^o$$

4. Compute dynamics active lateral earth pressure by Mononobe-Okabe Method

$$P_{total} = \frac{1}{2}\gamma H^2\frac{\cos^2(\phi-\psi-\alpha)(1\pm\alpha_v)}{\cos\psi\cos^2\alpha\cos(\delta+\alpha+\psi)}\times\frac{1}{\left\{1+\left[\frac{\sin(\phi+\delta)\sin(\phi-i-\psi)}{\cos(\alpha-i)\cos(\delta+\alpha+\psi)}\right]^{\frac{1}{2}}\right\}^2}$$

$P = \frac{1}{2}\times17.3\times6^2\times0.321 = 100.92\ kN/m$

5. Compute weight of wall

$W = \frac{1}{2}\gamma\ H2\ K_{ae}\ \{(\cos(\delta)-\sin(\delta)\tan\phi_b\ )/(\tan\phi_b-\tan\ \psi)\}$
$= \frac{1}{2}.\ 17.3\times6^2\times0.321\times1.331 = 2301\ kN/m$

6. Apply a factor of safety 1.5 to the calculated weight

$W_{req} = 1.5\times2301\ kN/m = 1150.5\ kN/m$

7. Critique Richard and Elm do not require stability of the wall.
   FOS = 1.5 in sliding only

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COMPARISION OF PRW METHOD AND RE METHOD

Orange County, CA.
El - Centro Earthquake
base width = 3.15m
$\alpha_{max} = 0.348g$
cutoff acc. = 0.149g

Permissible Displacement = 300 * α_{max} (mm) = 10.44cm

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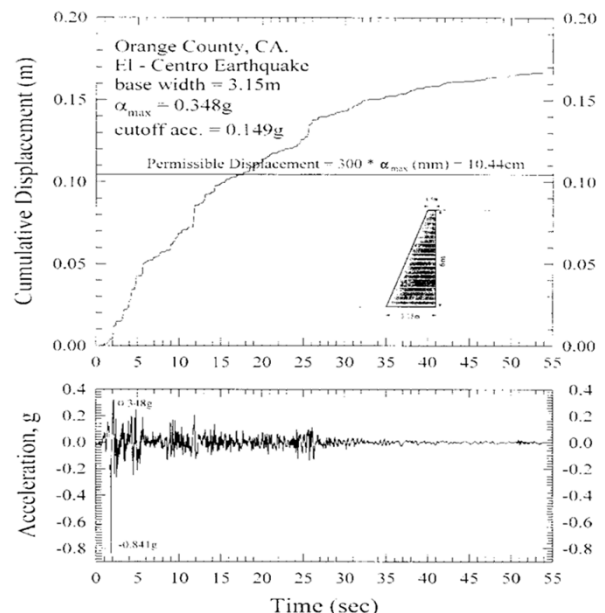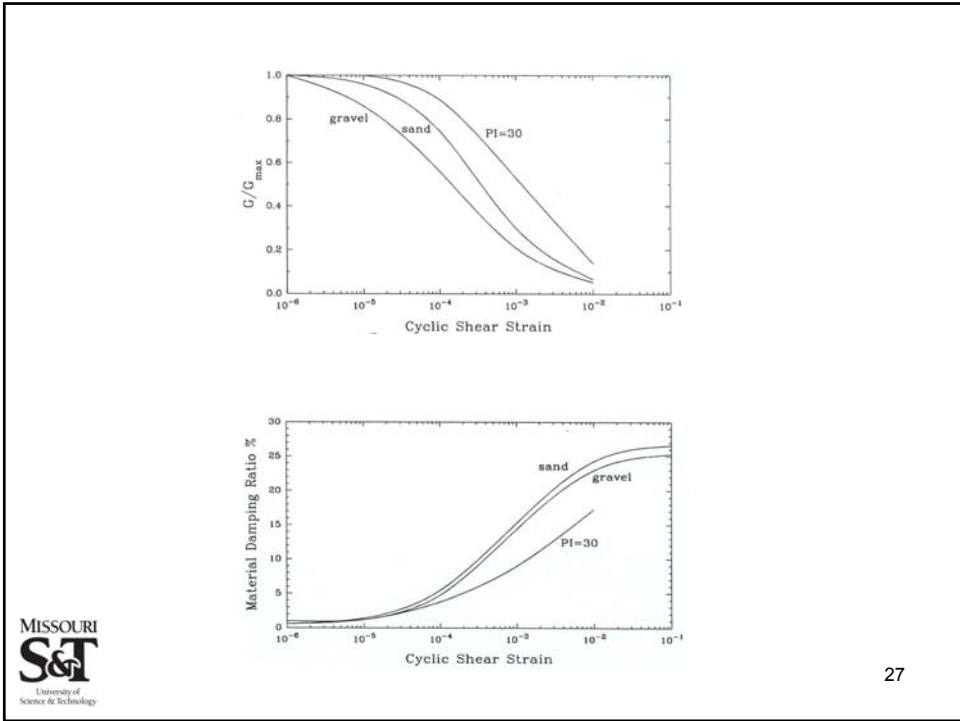
STUDIES BY RAFNSSON (1991)
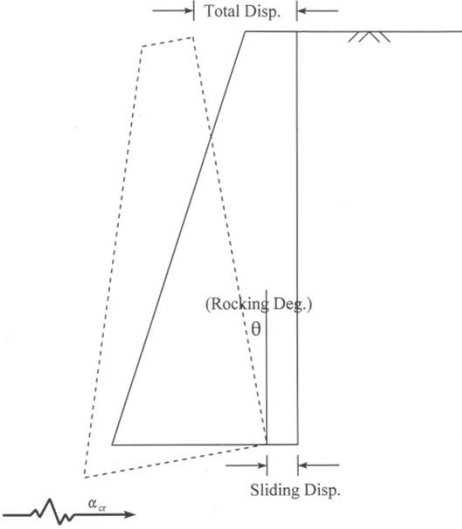
WU'S MODEL

1. Wall is rigid

2. Wall is long enough for neglecting the end effect

3. Rotation about the heel

4. The mass of backfill material participating in the wall motion is neglected

5. Simultaneous sliding and rocking motions occur

6. Real ground motion is considered

7. Backfill soil provides driving force only

8. Submerged, perched water table and other conditions considered as per Eurocode (1994)

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(a) Static   (b) Dynamic
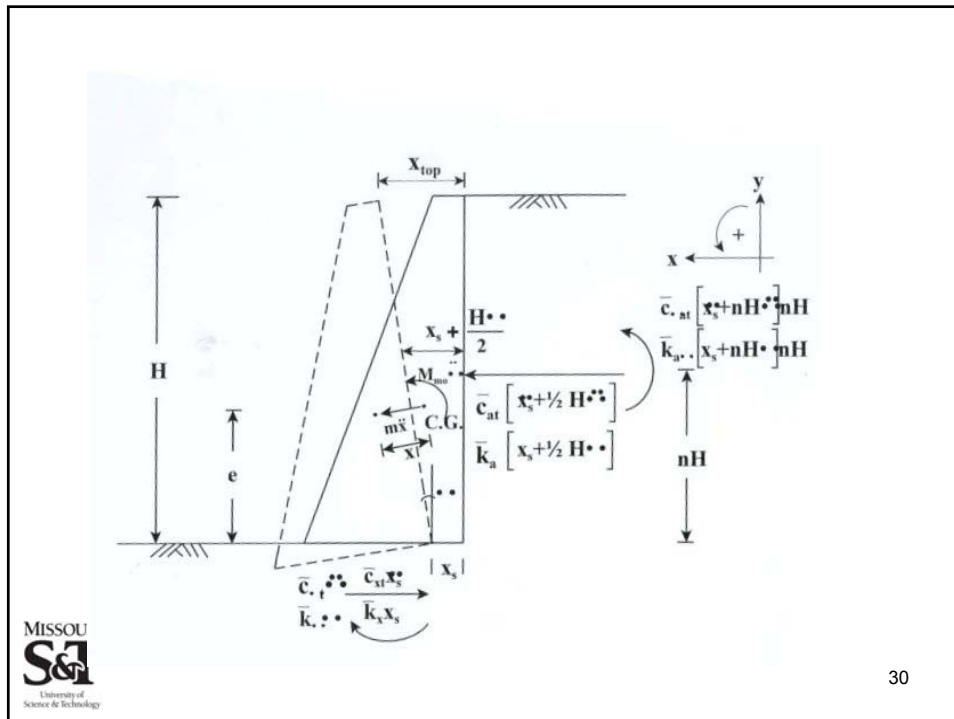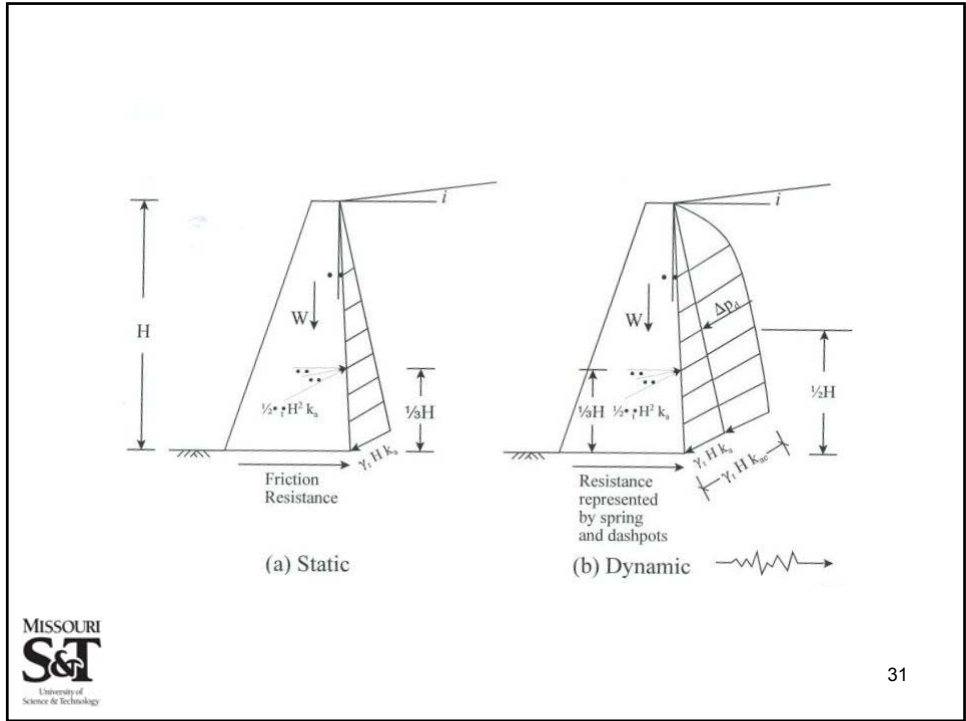
EQUATIONS OF MOTION

$$\begin{Bmatrix} m^* & \overset{*}{m}H_e \\ \overset{*}{m}H_e & \overset{**}{m}H_e^2 + \overline{I} \end{Bmatrix} \begin{Bmatrix} \ddot{x}_r \\ \ddot{\theta} \end{Bmatrix}$$

$$+ \begin{Bmatrix} c_{mxbs} + c_{rxbs} & 0 \\ 0 & c_{m\phi bs} + c_{r\phi bs} \end{Bmatrix} \begin{Bmatrix} \dot{x}_r \\ \dot{\theta} \end{Bmatrix}$$

$$+ \begin{Bmatrix} k_{xbs} & 0 \\ 0 & k_{\phi bs} \end{Bmatrix} \begin{Bmatrix} x_r \\ \theta \end{Bmatrix}$$

$$= \begin{Bmatrix} \overset{*}{m}\ddot{x}_g + \Delta p_d(t)\cos\delta \\ \overset{**}{m}H_e\ddot{x}_g + \Delta p_d(t)\cos\delta \times 0.5\,H \end{Bmatrix}$$

*   Add Δm
** Add ΔMMI

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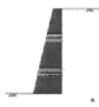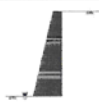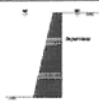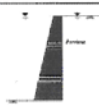
METHOD OF COMPUTATION

1. Wall dimensions are determined for given factors of safety under static condition.

2. Cumulative displacements and rotations of wall are then computed for a given ground motion.

3. The computed displacements are compared with the permissible displacements.

4. If the computed displacement is larger than permissible displacement, wall section will be redesigned for the permissible displacement

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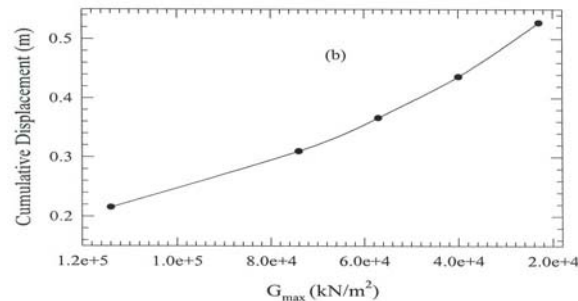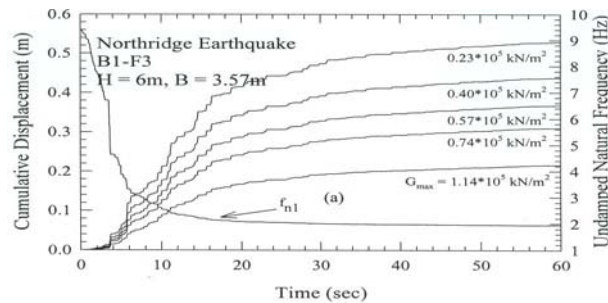
LOADING CONDITIONS AND CORRESPONDING PARAMETERS FOR DYNAMIC DISPLACEMENTS

	Field Conditions	Parameters Used for Dynamic Condition
	Condition 1 moist backfill moist base soil	$\gamma^* = \gamma_t$ $\psi = \tan^{-1}\left(\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 0$
	Condition 2 moist backfill sat. base soil	$\gamma^* = \gamma_t$ $\psi = \tan^{-1}\left(\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 0$
	Condition 3 submerged with **impervious** backfill	$\gamma^* = \gamma_{sat} - \gamma_w$ $\psi = \tan^{-1}\left(\dfrac{\gamma_{sat}}{\gamma_{sat} - \gamma_w}\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 7/12 * \alpha_h * \gamma_w * H'^2$
	Condition 4 submerged with **pervious** backfill	$\gamma^* = \gamma_{sat} - \gamma_w$ $\psi = \tan^{-1}\left(\dfrac{\gamma_d}{\gamma_{sat} - \gamma_w}\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 2*7/12 * \alpha_h * \gamma_w * H'^2$

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CONDITION 1

	Field Conditions	Parameters Used for Dynamic Condition
	Condition 1 moist backfill moist base soil	$\gamma^* = \gamma_t$ $\psi = \tan^{-1}\left(\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 0$

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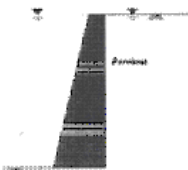
CONDITION 2

	Field Conditions	Parameters Used for Dynamic Condition
	Condition 2 moist backfill sat. base soil	$\gamma^* = \gamma_t$ $\psi = \tan^{-1}\left(\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 0$

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CONDITION 3

	Field Conditions	Parameters Used for Dynamic Condition
	Condition 3 submerged with **impervious** backfill	$\gamma^* = \gamma_{sat} - \gamma_w$ $\psi = \tan^{-1}\left(\dfrac{\gamma_{sat}}{\gamma_{sat} - \gamma_w}\dfrac{\alpha_h}{1 \pm \alpha_v}\right)$ $P_{wd}(t) = 7/12 * \alpha_h * \gamma_w * H'^2$

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CONDITION 4

	Field Conditions	Parameters Used for Dynamic Condition
	Condition 4 submerged with **pervious** backfill	$\gamma^* = \gamma_{sat} - \gamma_w$ $\psi = \tan^{-1}\left(\dfrac{\gamma_d}{\gamma_{sat}-\gamma_w}\dfrac{\alpha_h}{1\pm\alpha_v}\right)$ $P_{wd}(t) = 2*7/12 * \alpha_h * \gamma_w * H'^2$

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NONLINEAR BEHAVIOR

- **Soil stiffness in sliding**

- Soil stiffness in rocking

- **Material damping in sliding**

- Material damping in rocking.

- **Geometrical damping in sliding**

- Geometrical damping in rocking

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0.5m

Foundation soil (F3)
Well graded sand (SW)
γ_t=19.44 kN/M³
φ = 35.0°
δ = 23.3°
e = 0.46
w% = 8%
υ = 0.3

6m

Backfill (B1)
Compacted poorly
graded gravel -silt (GM)
φ = 33.0°
δ = 22.0°
e = 0.35
γ_t=21.60kN/M³
υ = 0.3
w% = 10%
γ_c=24.00kN/M³

3.57m

Fig. Dimension of reference wall and soil properties used.

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Fig. Sliding, rocking, and total displacements for reference wall

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COMPUTED DISPLACEMENTS FOR EL-CENTRO EARTHQUAKE (Field Conditions 1-4)

Computed displacements for seven field conditions (b=3.57m).

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COMPUTED DISPLACEMENTS FOR LOMA PRIETA EARTHQUAKE (Field Conditions 1-4)

Computed displacements for seven field conditions (b=3.57m).

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COMPUTED DISPLACEMENTS FOR NORTHRIDGE EARTHQUAKE (Field Conditions 1-4)
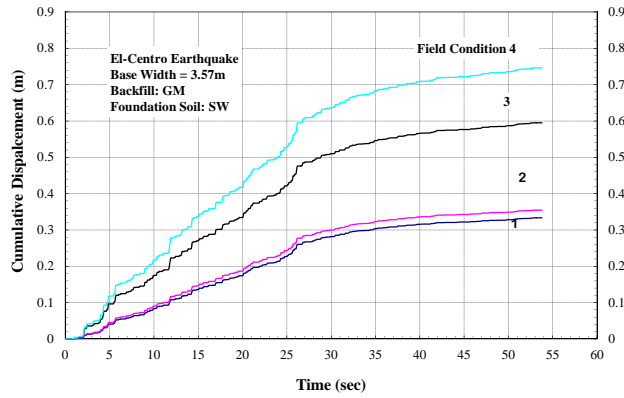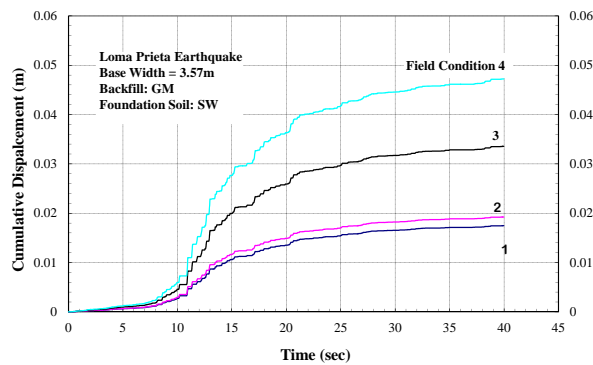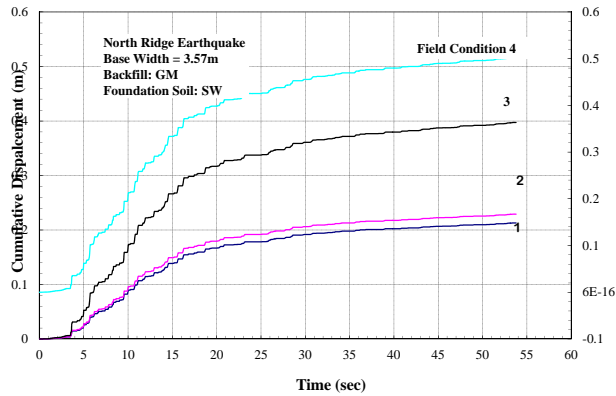
Computed displacements for seven field conditions (b=3.57m).

COMPUTED DISPLACEMENTS AFTER 3 EARTHQUAKES

Field Conditions	Wall Displacement (cm)		
	El-Centro	North Ridge	Loma Prieta
1	33.32	21.55	1.75
2	35.46	23.16	1.92
3	59.51	40.13	3.35
4	74.61	50.79	4.72
Permissible Displacement According to EUROCODE			
α_{max} (g)	0.349	0.344	0.113
Permissible Displacement (cm)	10.47	10.32	3.39

Figure 4.4. Retaining walls with seven typical field conditions a) field condition 1: moist backfill and foundation soil, b) field condition 2: moist backfill and saturated foundation soil c) field conditions 3 and 4: fully submerged wall with impervious and pervious backfill, d) field conditions 5 and 6: perched condition with impervious and pervious backfill, and e) field condition 7: saturated backfill with a sloping drain installed.

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Displacement Based Analysis and Design of Rigid Retaining Walls During Earthquakes-13

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Computed displacements for seven field conditions
(b=3.57m).

Fig. Wall section and soil properties used in the centrifuge test.

Fig. Comparison with model test; a) computed displacements compared with observed value by Zeng (1998), b) input ground motion for centrifuge test

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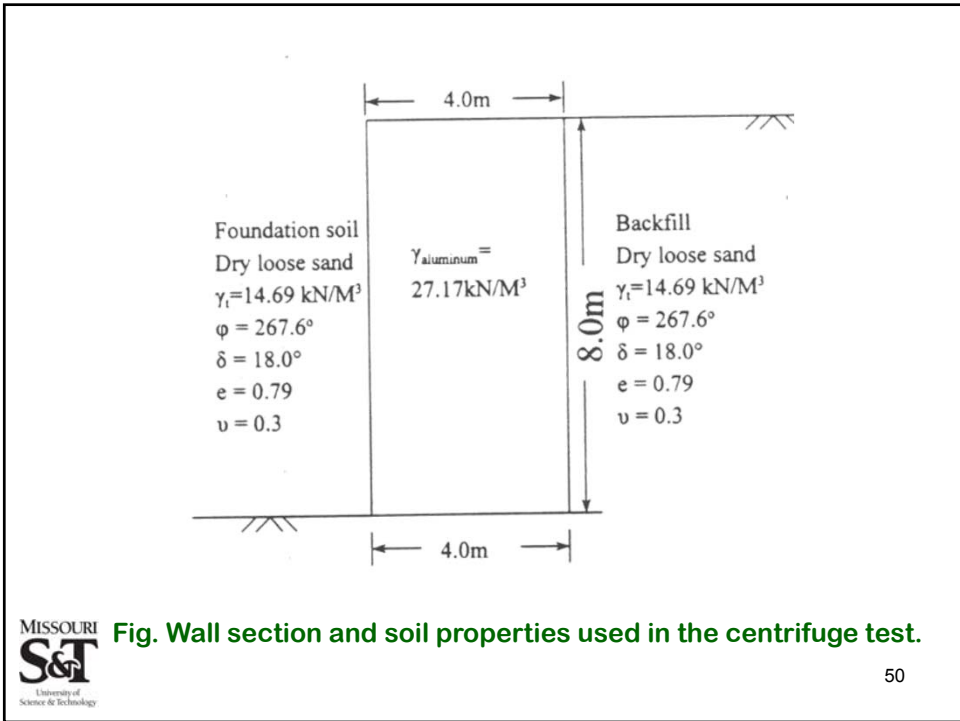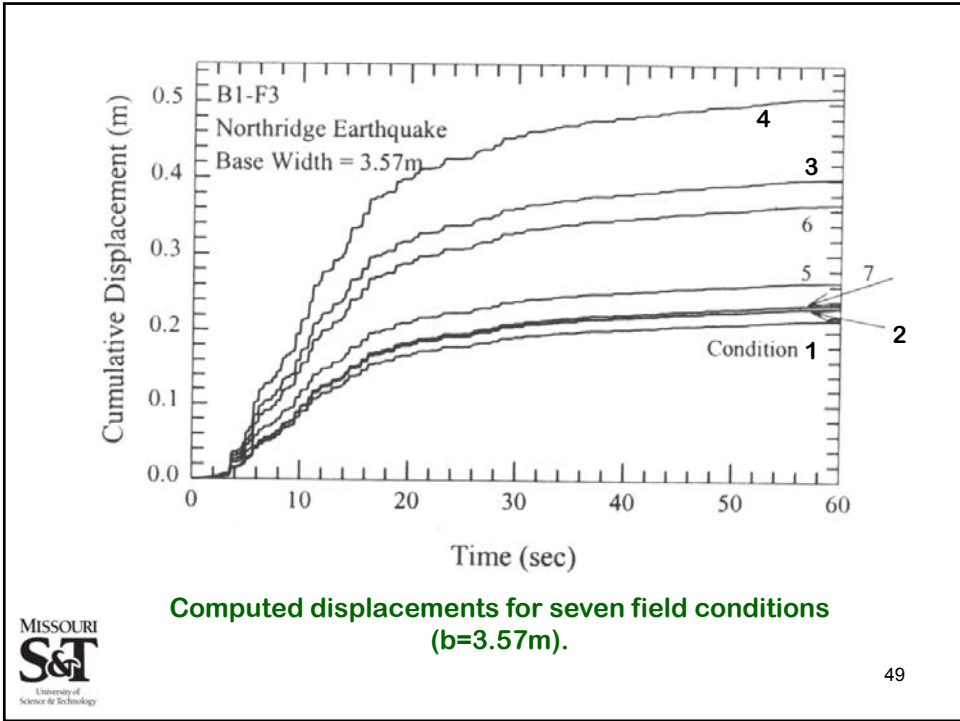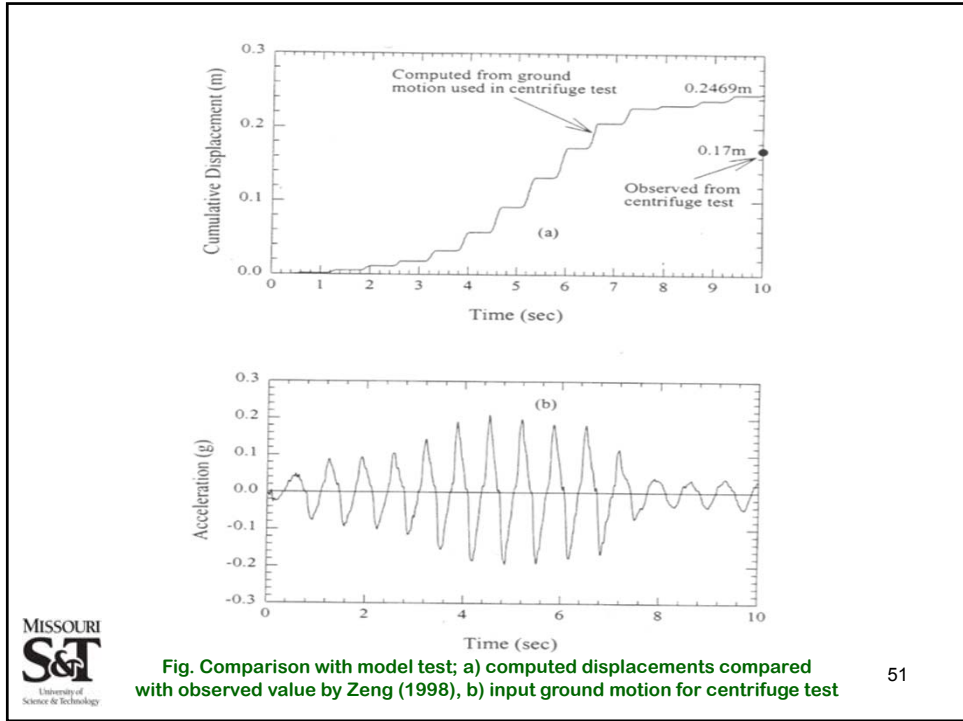
Table. Engineering properties for both foundation soil and backfill (Naval, 1986)

FOUNDATION SOIL (F)

	Soil Type	γ_d kN/M³	φ deg	δ deg	void ratio	v	c kN/M²	PI	W%
F-1	GW	21.07	37.5	25.0	0.25	0.3	-	-	6
F-2	GP	19.18	36.0	24.0	0.36	0.3	-	-	6
F-3	SW	18.00	35.0	23.3	0.46	0.3	-	-	8
F-4	SP	16.82	34.0	22.7	0.56	0.3	-	-	10
F-5	SM	15.70	33.0	22.0	0.68	0.3	-	4	15
F-6	SC	14.00	30.0	20.0	0.88	0.3	-	13	25
F-7	ML	14.15	32.0	21.3	0.85	0.3	9.57	4	14

BACKFILL (B)

	Soil Type	γ_d kN/M³	φ deg	δ deg	void ratio	v	c kN/M²	PI	W%
B-1	GM	19.6	33.0	22.0	0.35	0.3	-	-	10
B-2	GP	18.9	34.0	22.7	0.40	0.3	-	-	8
B-3	SP	15.6	34.0	22.7	0.69	0.3	-	-	8

* All properties for backfill are for the condition of 90 percent of the "Standard Proctor".

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VERTICAL vs. INCLINED WALLS BEHAVIOUR

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Table. Foundation Widths of 21-walls for static forces

Soil Comb.	Base Width (m)					
	Vertical	-1 degree	-2 degree	-3 degree	-4 degree	-5 degree
B1-F1	3.22	3.17	3.12	3.17	3.12	2.96
B1-F2	3.42	3.47	3.31	3.26	3.20	3.24
B1-F3	3.57	3.51	3.46	3.40	3.34	3.38
B1-F4	3.71	3.65	3.69	3.63	3.66	3.60
B1-F5	4.07	4.01	4.05	3.98	3.92	3.95
B1-F6	4.61	4.64	4.57	4.49	4.52	4.44
B1-F7	4.05	3.99	3.92	3.85	3.78	3.71
B2-F1	2.85	2.80	2.76	2.71	2.76	2.61
B2-F2	3.13	2.98	2.93	2.88	2.93	2.77
B2-F3	3.17	3.12	3.06	3.01	2.95	2.99
B2-F4	3.39	3.34	3.28	3.32	3.26	3.30
B2-F5	3.74	3.69	3.63	3.67	3.6	3.54
B2-F6	4.23	4.16	4.10	4.12	4.05	3.98
B2-F7	3.61	3.64	3.58	3.42	3.35	3.38
B3-F1	2.27	2.23	2.19	2.15	2.11	2.07
B3-F2	2.52	2.38	2.43	2.29	2.25	2.20
B3-F3	2.63	2.59	2.44	2.40	2.45	2.40
B3-F4	2.93	2.79	2.74	2.69	2.74	2.69
B3-F5	3.16	3.01	2.96	3.01	2.96	3.00
B3-F6	4.56	4.60	4.55	4.49	4.53	4.47
B3-F7	2.89	2.84	2.79	2.83	2.68	2.62

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Fig. Cumulative displacements computed for different angles of inclination at the back of the reference wall subjected to Northridge earthquake condition

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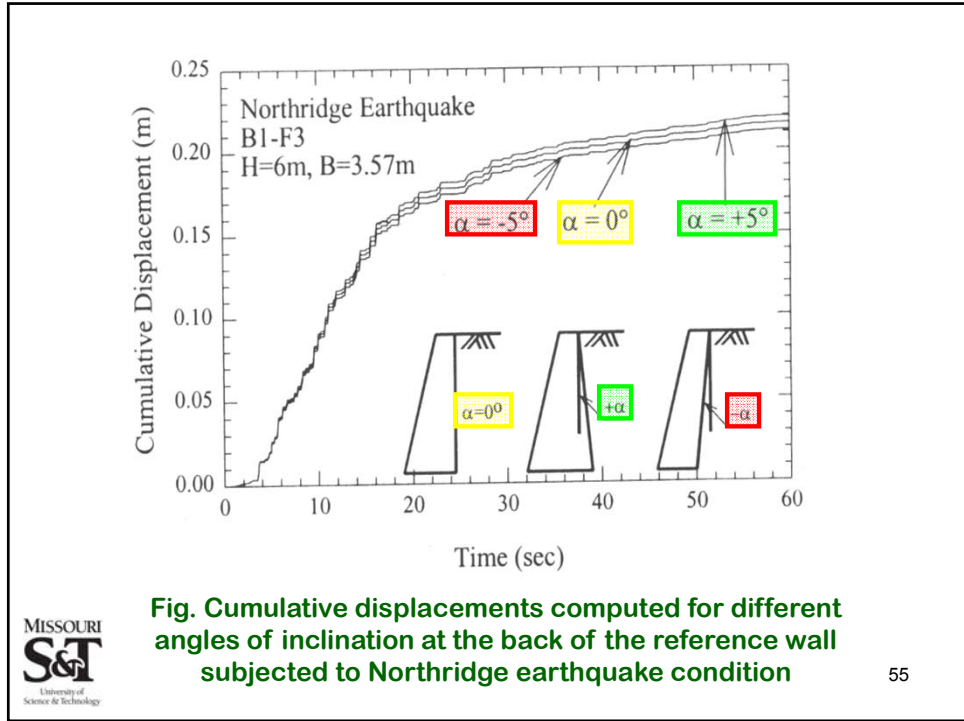
Table. Cumulative displacement for three angles of inclination at the back of a wall subjected to Northridge earthquake condition (B=3.57m)

Inclination angle (degree)	Base width (m)	Cumulative Displacement by Fixed Base Width (3.57m)			
		Sliding (m)	Rocking (degree)	Rocking (m)	Total (m)
+5.00°	3.81	0.0820	1.31	0.1374	0.2194
+3.75°	3.76	0.0820	1.30	0.1366	0.2186
+2.50°	3.70	0.0815	1.30	0.1361	0.2176
+1.25°	3.63	0.0808	1.29	0.1355	0.2163
0.00°	3.57	0.0808	1.29	0.1347	0.2155
-1.25°	3.50	0.0806	1.28	0.1338	0.2144
-2.50°	3.43	0.0805	1.27	0.1329	0.2134
-3.75°	3.35	0.0803	1.26	0.1320	0.2123
-5.00°	3.38	0.0801	1.25	0.1311	0.2112
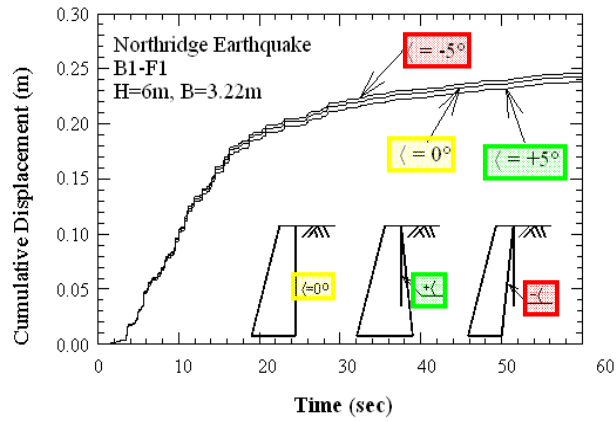
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Fig. Cumulative displacements computed for different angles of inclination at the back of the reference wall subjected to Northridge earthquake condition

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Fig. Cumulative displacements computed for different angles of inclination at the back of the reference wall subjected to Northridge earthquake condition

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Fig. Cumulative displacements of walls (B3-F7) with different inclinations with the vertical (Wu 1999)

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Fig. Cumulative displacements of walls (B1-F6) with different inclinations with the vertical (Wu 1999)

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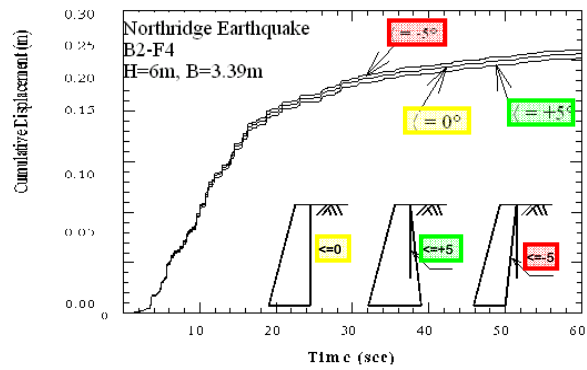
Table C1. Cumulative displacements for walls 4 to 10m high with B1-F1 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.08)	1	0.0895	2.52 (0.1760)	0.2655	0.0604	1.62 (0.1128)	0.1732	0.0052	0.11 (0.0074)	0.0126
	2	0.0940	2.71 (0.1889)	0.2829	0.0642	1.75 (0.1221)	0.1862	0.0057	0.12 (0.0083)	0.0140
	7	0.0960	2.76 (0.1928)	0.2887	0.0652	1.79 (0.1247)	0.1899	0.0058	0.12 (0.0085)	0.0143
5 (2.60)	1	0.1058	2.54 (0.2515)	0.3273	0.0722	1.65 (0.1439)	0.2160	0.0068	0.12 (0.0104)	0.0172
	2	0.1118	2.71 (0.2365)	0.3483	0.0766	1.77 (0.1546)	0.2311	0.0074	0.13 (0.0113)	0.0187
	7	0.1136	2.76 (0.2412)	0.3548	0.0779	1.81 (0.1578)	0.2357	0.0075	0.13 (0.0116)	0.191
6 (3.22)	1	0.1184	2.37 (0.2483)	0.3667	0.0809	1.54 (0.1615)	0.2424	0.0082	0.12 (0.0124)	0.0206
	2	0.1235	2.53 (0.2654)	0.3889	0.0849	1.66 (0.1740)	0.2589	0.0087	0.13 (0.0138)	0.0225
	7	0.1225	2.58 (0.2736)	0.3961	0.0863	1.70 (0.1776)	0.2639	0.0089	0.13 (0.0140)	0.0229
7 (3.84)	1	0.1281	2.25 (0.2745)	0.4026	0.0880	1.47 (0.1794)	0.2674	0.0094	0.12 (0.0147)	0.0241
	2	0.1335	2.39 (0.2923)	0.4258	0.0922	1.58 (0.1924)	0.2846	0.0101	0.13 (0.0163)	0.0264
	7	0.1357	2.44 (0.2979)	0.4336	0.0937	1.61 (0.1964)	0.2901	0.0103	0.14 (0.0167)	0.0270
8 (4.56)	1	0.1353	2.05 (0.2863)	0.4216	0.0931	1.34 (0.1871)	0.2802	0.0104	0.12 (0.0161)	0.0265
	2	0.1407	2.18 (0.3048)	0.4455	0.0970	1.44 (0.2011)	0.2981	0.0112	0.13 (0.0178)	0.0289
	7	0.1428	2.22 (0.3106)	0.4535	0.0985	1.47 (0.2052)	0.3037	0.0114	0.13 (0.0181)	0.0295
9 (5.08)	1	0.1442	2.05 (0.3213)	0.4655	0.0998	1.35 (0.2122)	0.3120	0.0117	0.12 (0.0192)	0.0309
	2	0.1498	2.17 (0.3405)	0.4903	0.1035	1.44 (0.2267)	0.3303	0.0127	0.13 (0.0211)	0.0339
	7	0.1521	2.21 (0.3470)	0.4991	0.1051	1.47 (0.2312)	0.3364	0.0130	0.14 (0.0216)	0.0345
10 (5.80)	1	0.1499	1.91 (0.3373)	0.4816	0.1034	1.26 (0.2195)	0.3229	0.0128	0.12 (0.0205)	0.0334
	2	0.1558	2.01 (0.3515)	0.5073	0.1073	1.34 (0.2342)	0.3415	0.0138	0.13 (0.0227)	0.0365
	7	0.1581	2.05 (0.3581)	0.5162	0.1089	1.37 (0.2388)	0.3477	0.0141	0.13 (0.0232)	0.0372

[1] H: height of wall, B: base width
[2] Permissible displacements for three earthquakes according to Eurocode = $300 \times \alpha_{max}$

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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OBSERVATIONS

1. INCLINED AND VERTICAL WALLS EXPERIENCE DISPLACEMENT OF THE SAME ORDER.

2. WALLS WITH NEGATIVE INCLINATION ARE RECOMMENDED.

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Table C2. Cumulative displacements for walls 4 to 10m high with B1-F2 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (2.11)	1	0.1035	2.91 (0.2030)	0.3065	0.0709	1.90 (0.1326)	0.2036	0.0065	0.13 (0.0094)	0.0160
	2	0.1092	3.09 (0.2154)	0.3246	0.0751	2.03 (0.1415)	0.2166	0.0071	0.15 (0.0103)	0.0175
	7	0.1109	3.14 (0.2195)	0.3304	0.0763	2.07 (0.1444)	0.2207	0.0073	0.15 (0.0106)	0.0178
5 (2.77)	1	0.1186	2.64 (0.2306)	0.3492	0.0812	1.73 (0.1505)	0.2317	0.0082	0.13 (0.0115)	0.0196
	2	0.1235	2.81 (0.2453)	0.3689	0.0850	1.85 (0.1614)	0.2464	0.0087	0.15 (0.0128)	0.0215
	7	0.1255	2.86 (0.2499)	0.3754	0.0865	1.88 (0.1644)	0.2510	0.0089	0.15 (0.0131)	0.0220
6 (3.42)	1	0.1303	2.46 (0.2577)	0.3880	0.0895	1.62 (0.1690)	0.2585	0.0096	0.13 (0.0138)	0.0234
	2	0.1355	2.61 (0.2734)	0.4089	0.0935	1.72 (0.1806)	0.2741	0.0103	0.15 (0.0153)	0.0256
	7	0.1375	2.66 (0.2785)	0.4160	0.0950	1.76 (0.1841)	0.2791	0.0105	0.15 (0.0156)	0.0261
7 (4.17)	1	0.1386	2.21 (0.2704)	0.4100	0.0954	1.45 (0.1172)	0.2726	0.0107	0.12 (0.0152)	0.0259
	2	0.1439	2.35 (0.2869)	0.4308	0.0996	1.55 (0.1896)	0.2892	0.0116	0.14 (0.0168)	0.0284
	7	0.1460	2.39 (0.2922)	0.4382	0.1011	1.58 (0.1932)	0.2944	0.0118	0.14 (0.0171)	0.0289
8 (4.72)	1	0.1489	2.19 (0.3064)	0.4553	0.1031	1.45 (0.2028)	0.3058	0.0123	0.13 (0.0185)	0.0309
	2	0.1545	2.32 (0.3237)	0.4782	0.1067	1.55 (0.2158)	0.3225	0.0134	0.15 (0.0204)	0.0337
	7	0.1568	2.36 (0.3296)	0.4864	0.1083	1.57 (0.2199)	0.3282	0.0136	0.15 (0.0208)	0.0343
9 (5.48)	1	0.1556	2.02 (0.3176)	0.4732	0.1072	1.34 (0.2105)	0.3177	0.0136	0.13 (0.0200)	0.0336
	2	0.1610	2.13 (0.3351)	0.4961	0.1118	1.42 (0.2235)	0.3353	0.0146	0.14 (0.0220)	0.0366
	7	0.1633	2.17 (0.3412)	0.5045	0.1134	1.45 (0.2277)	0.3412	0.0149	0.14 (0.0224)	0.0373
10 (6.03)	1	0.1636	2.00 (0.3482)	0.5118	0.1140	1.33 (0.2320)	0.3460	0.0152	0.13 (0.0233)	0.0385
	2	0.1690	2.10 (0.3659)	0.5349	0.1176	1.41 (0.2460)	0.3636	0.0161	0.15 (0.0256)	0.0417
	7	0.1741	2.13 (0.3725)	0.5439	0.1194	1.44 (0.2506)	0.3699	0.0163	0.15 (0.0262)	0.0425

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)   = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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Table C3. Cumulative displacements for walls 4 to 10m high with B1-F3 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

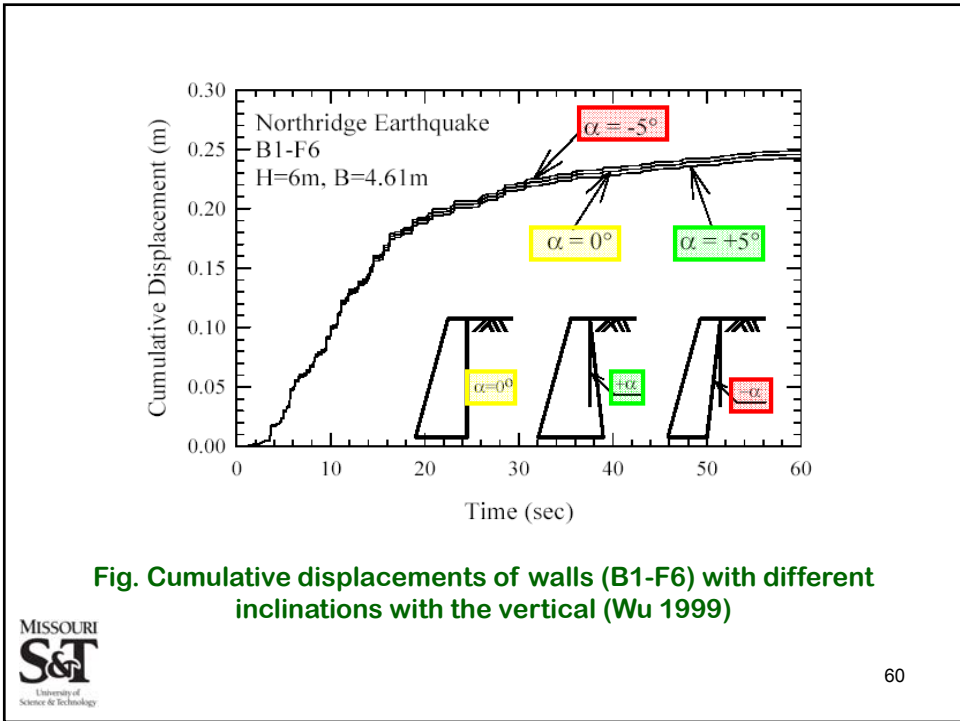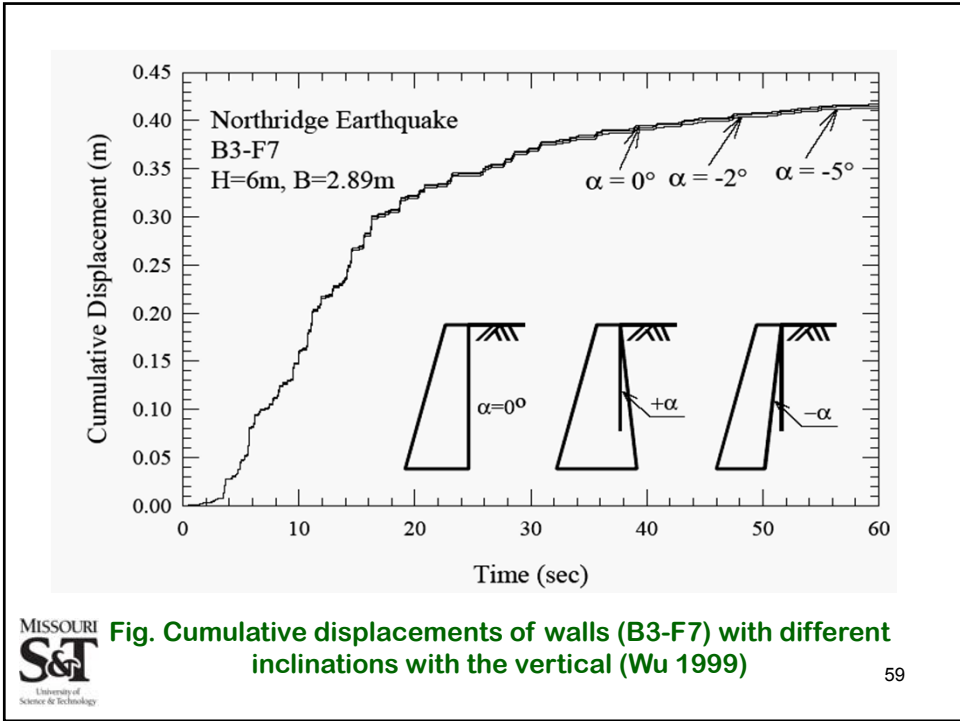| H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (2.21)	1	0.0937	2.37 (0.1655)	0.2592	0.0622	1.48 (0.1034)	0.1656	0.0052	0.09 (0.0063)	0.0115
	2	0.0983	2.55 (0.1781)	0.2764	0.0667	1.61 (0.1126)	0.1793	0.0056	0.10 (0.0070)	0.0126
	7	0.1000	2.60 (0.1816)	0.2816	0.0682	1.64 (0.1148)	0.1830	0.0057	0.10 (0.0072)	0.0129
5 (2.99)	1	0.1050	2.02 (0.1764)	0.2814	0.0706	1.25 (0.1094)	0.1800	0.0063	0.08 (0.0072)	0.0135
	2	0.1112	2.18 (0.1898)	0.3010	0.0750	1.37 (0.1194)	0.1944	0.0070	0.09 (0.0080)	0.0150
	7	0.1134	2.22 (0.1937)	0.3071	0.0763	1.40 (0.1219)	0.1982	0.0071	0.09 (0.0081)	0.0152
6 (3.57)	1	0.1201	2.03 (0.2131)	0.3332	0.0808	1.29 (0.1347)	0.2155	0.0079	0.09 (0.0096)	0.0175
	2	0.1257	2.19 (0.2289)	0.3546	0.0856	1.39 (0.1505)	0.2316	0.0086	0.10 (0.0106)	0.0192
	7	0.1277	2.23 (0.2334)	0.3611	0.0870	1.42 (0.1491)	0.2361	0.0087	0.10 (0.0109)	0.0196
7 (4.25)	1	0.1300	1.93 (0.2360)	0.3660	0.0887	1.23 (0.1501)	0.2388	0.0091	0.09 (0.0115)	0.0206
	2	0.1357	2.07 (0.2527)	0.3884	0.0931	1.33 (0.1623)	0.2554	0.0098	0.10 (0.0128)	0.0226
	7	0.1387	2.11 (0.2567)	0.3954	0.0946	1.36 (0.1657)	0.2603	0.0100	0.11 (0.0130)	0.0230
8 (4.93)	1	0.1386	1.84 (0.2573)	0.3959	0.0950	1.18 (0.1649)	0.2599	0.0103	0.10 (0.0133)	0.0236
	2	0.1442	1.97 (0.2746)	0.4188	0.0989	1.28 (0.1781)	0.2770	0.0110	0.11 (0.0147)	0.0257
	7	0.1464	2.00 (0.2798)	0.4262	0.1005	1.30 (0.1816)	0.2821	0.0111	0.11 (0.0151)	0.0262
9 (5.61)	1	0.1460	1.76 (0.2772)	0.4232	0.1002	1.14 (0.1794)	0.2796	0.0113	0.10 (0.0152)	0.0265
	2	0.1519	1.88 (0.2949)	0.4468	0.1047	1.23 (0.1925)	0.2972	0.0123	0.11 (0.0168)	0.0291
	7	0.1542	1.91 (0.3022)	0.4564	0.1063	1.25 (0.1963)	0.3026	0.0125	0.11 (0.0171)	0.0296
10 (6.38)	1	0.1518	1.64 (0.2870)	0.4388	0.1043	1.07 (0.1861)	0.2904	0.0124	0.09 (0.0165)	0.0289
	2	0.1579	1.75 (0.3050)	0.4629	0.1085	1.15 (0.1997)	0.3082	0.0134	0.10 (0.0182)	0.0316
	7	0.1603	1.78 (0.3105)	0.4708	0.1102	1.17 (0.2035)	0.3137	0.0136	0.11 (0.0185)	0.0321

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)   = 0.1032m
Loma-Prieta = 0.113*300 (mm) =0.0339m

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Table C4. Cumulative displacements for walls 4 to 10m high with B1-F4 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.40)	1	0.1014	2.35 (0.1638)	0.2652	0.0684	1.46 (0.1022)	0.1706	0.0059	0.09 (0.0065)	0.0124
	2	0.1075	2.52 (0.1757)	0.2832	0.0727	1.59 (0.1111)	0.1838	0.0065	0.10 (0.0072)	0.0136
	7	0.1092	2.56 (0.1790)	0.2882	0.0739	1.62 (0.1134)	0.1873	0.0066	0.11 (0.0073)	0.0139
5 (3.10)	1	0.1169	2.18 (0.1902)	0.3071	0.0786	1.37 (0.1198)	0.1984	0.0075	0.09 (0.0082)	0.0158
	2	0.1226	2.35 (0.2048)	0.3274	0.0835	1.49 (0.1301)	0.2136	0.0082	0.11 (0.0092)	0.0174
	7	0.1245	2.39 (0.2087)	0.3321	0.0848	1.52 (0.1328)	0.2176	0.0083	0.11 (0.0094)	0.0177
6 (3.71)	1	0.1307	2.18 (0.2279)	0.3586	0.0893	1.39 (0.1457)	0.2350	0.0091	0.10 (0.0110)	0.0201
	2	0.1363	2.33 (0.2436)	0.3799	0.0937	1.50 (0.1573)	0.2510	0.0098	0.12 (0.0122)	0.0220
	7	0.1384	2.37 (0.2481)	0.3865	0.0952	1.53 (0.1604)	0.2556	0.0099	0.12 (0.0125)	0.0224
7 (4.50)	1	0.1389	1.96 (0.2399)	0.3788	0.0951	1.26 (0.1536)	0.2488	0.0102	0.10 (0.0122)	0.0224
	2	0.1446	2.10 (0.2562)	0.4008	0.0995	1.36 (0.1657)	0.2653	0.0109	0.11 (0.0136)	0.0246
	7	0.1467	2.14 (0.2609)	0.4076	0.1011	1.38 (0.1689)	0.2700	0.0111	0.11 (0.0139)	0.0250
8 (5.21)	1	0.1477	1.87 (0.2618)	0.4095	0.1017	1.21 (0.1690)	0.2707	0.0116	0.10 (0.0142)	0.0258
	2	0.1534	2.00 (0.2786)	0.4320	0.1059	1.30 (0.1818)	0.2878	0.0125	0.11 (0.0158)	0.0283
	7	0.1556	2.03 (0.2836)	0.4392	0.1075	1.33 (0.1853)	0.2928	0.0126	0.12 (0.0161)	0.0288
9 (5.81)	1	0.1567	1.85 (0.2908)	0.4475	0.1080	1.21 (0.1902)	0.2981	0.0131	0.11 (0.0169)	0.0300
	2	0.1627	1.96 (0.3081)	0.4708	0.1128	1.29 (0.2029)	0.3157	0.0141	0.12 (0.0187)	0.0328
	7	0.1650	2.00 (0.3136)	0.4786	0.1145	1.32 (0.2067)	0.3212	0.143	0.12 (0.0191)	0.0334
10 (6.60)	1	0.1624	1.72 (0.3003)	0.4628	0.1114	1.13 (0.1971)	0.3085	0.0143	0.10 (0.0182)	0.0352
	2	0.1683	1.82 (0.3175)	0.4858	0.1170	1.20 (0.2098)	0.3267	0.0154	0.12 (0.0202)	0.0356
	7	0.1706	1.85 (0.3231)	0.4938	0.1186	1.22 (0.2137)	0.3323	0.0156	0.12 (0.0206)	0.0362

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)   = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

Table C5. Cumulative displacements for walls 4 to 10m high with B1-F5 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.62)	1	0.1111	2.36 (0.1647)	0.2757	0.0748	1.47 (0.1029)	0.1777	0.0069	0.10 (0.0068)	0.0137
	2	0.1174	2.55 (0.1782)	0.2955	0.0799	1.61 (0.1125)	0.1924	0.0076	0.11 (0.0077)	0.0153
	7	0.1191	2.60 (0.1813)	0.3004	0.0811	1.65 (0.1147)	0.1958	0.0077	0.11 (0.0079)	0.0156
5 (3.34)	1	0.1260	2.22 (0.1941)	0.3201	0.0857	1.41 (0.1227)	0.2083	0.0086	0.10 (0.0089)	0.0176
	2	0.1321	2.40 (0.2093)	0.3414	0.0906	1.53 (0.1338)	0.2243	0.0093	0.12 (0.0101)	0.0194
	7	0.1340	2.44 (0.2130)	0.3470	0.0919	1.56 (0.1363)	0.2283	0.0095	0.12 (0.0103)	0.0198
6 (4.07)	1	0.1379	2.11 (0.2211)	0.3590	0.0944	1.35 (0.1414)	0.2358	0.0101	0.11 (0.0111)	0.0212
	2	0.1439	2.26 (0.2372)	0.3811	0.0992	1.46 (0.1532)	0.2524	0.0110	0.12 (0.0124)	0.0234
	7	0.1460	2.30 (0.2412)	0.3872	0.1006	1.49 (0.1561)	0.2567	0.0112	0.12 (0.0126)	0.0238
7 (4.80)	1	0.1481	2.01 (0.2454)	0.3935	0.1019	1.30 (0.1586)	0.2605	0.0117	0.11 (0.0132)	0.0249
	2	0.1543	2.14 (0.2620)	0.4163	0.1064	1.40 (0.1713)	0.2771	0.0127	0.12 (0.0148)	0.0275
	7	0.1564	2.18 (0.2665)	0.4230	0.1079	1.43 (0.1744)	0.2823	0.0129	0.12 (0.0151)	0.0280
8 (5.53)	1	0.1571	1.92 (0.2674)	0.4245	0.1079	1.25 (0.1745)	0.2824	0.0132	0.11 (0.0155)	0.0287
	2	0.1632	2.04 (0.2845)	0.4477	0.1136	1.34 (0.1868)	0.3004	0.0144	0.12 (0.0173)	0.0316
	7	0.1655	2.07 (0.2893)	0.4548	0.1152	1.36 (0.1902)	0.3054	0.0146	0.13 (0.0176)	0.0322
9 (6.26)	1	0.1647	1.83 (0.2873)	0.4520	0.1144	1.20 (0.1883)	0.3027	0.0147	0.11 (0.0177)	0.0324
	2	0.1709	1.94 (0.3044)	0.4753	0.1189	1.29 (0.2021)	0.3207	0.0158	0.13 (0.0198)	0.0356
	7	0.1732	1.97 (0.3095)	0.4827	0.1203	1.31 (0.2056)	0.3259	0.0161	0.13 (0.0201)	0.0362
10 (6.99)	1	0.1715	1.75 (0.3052)	0.4768	0.1189	1.16 (0.2021)	0.3209	0.0160	0.11 (0.0200)	0.0360
	2	0.1776	1.85 (0.3225)	0.5000	0.1233	1.23 (0.2155)	0.3389	0.0170	0.13 (0.0223)	0.0393
	7	0.1799	1.88 (0.3278)	0.5077	0.1250	1.26 (0.2193)	0.3443	0.0172	0.13 (0.0227)	0.0399

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)   = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

Table C6. Cumulative displacements for walls 4 to 10m high with B1-F6 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.78)	1	0.1295	2.75 (0.1916)	0.3211	0.0889	1.76 (0.1227)	0.2116	0.0090	0.13 (0.0091)	0.0181
	2	0.1358	2.96 (0.2068)	0.3427	0.0934	1.92 (0.1343)	0.2277	0.0098	0.15 (0.0103)	0.0202
	7	0.1377	3.01 (0.2102)	0.3479	0.0947	1.96 (0.1366)	0.2313	0.0100	0.15 (0.0105)	0.0205
5 (3.69)	1	0.1408	2.15 (0.2055)	0.3463	0.0966	1.51 (0.1317)	0.2283	0.0106	0.12 (0.0105)	0.0211
	2	0.1476	2.54 (0.2217)	0.3693	0.1019	1.65 (0.1441)	0.2460	0.0119	0.14 (0.0118)	0.0237
	7	0.1496	2.58 (0.2252)	0.3747	0.1032	1.68 (0.1466)	0.2498	0.01201	0.14 (0.0120)	0.0241
6 (4.61)	1	0.1508	2.10 (0.2200)	0.3708	0.1035	1.36 (0.1421)	0.2456	0.0125	0.11 (0.0119)	00244
	2	0.1578	2.26 (0.2309)	0.3947	0.1092	1.48 (0.1548)	0.2640	0.0136	0.13 (0.0138)	0.0274
	7	0.1598	2.30 (0.2406)	0.4004	0.1106	1.50 (0.1574)	0.2680	0.0138	0.13 (0.0140)	0.0278
7 (5.53)	1	0.1590	1.92 (0.2341)	0.3931	0.1098	1.25 (0.1521)	0.2619	0.0139	0.11 (0.0138)	0.0277
	2	0.1662	2.05 (0.2511)	0.4173	0.1153	1.35 (0.1654)	0.2807	0.0152	0.13 (0.0157)	0.0310
	7	0.1683	2.09 (0.2549)	0.4232	0.1167	1.38 (0.1681)	0.2848	0.0154	0.13 (0.0160)	0.0314
8 (6.45)	1	0.1663	1.77 (0.2470)	0.4134	0.1150	1.16 (0.1619)	0.2769	0.0154	0.11 (0.0156)	0.0310
	2	0.1734	1.89 (0.2641)	0.4376	0.1202	1.26 (0.1755)	0.2957	0.0165	0.13 (0.0178)	0.0343
	7	0.1756	1.92 (0.2681)	0.4436	0.1217	1.28 (0.1783)	0.3000	0.0167	0.13 (0.0181)	0.0348
9 (7.37)	1	0.1727	1.65 (0.2590)	0.4317	0.1195	1.11 (0.1711)	0.2906	0.0165	0.11 (0.0175)	0.0340
	2	0.1799	1.76 (0.2759)	0.4558	0.1242	1.18 (0.1850)	0.3092	0.0177	0.13 (0.0198)	0.0375
	7	0.1821	1.78 (0.2799)	0.4620	0.1258	1.20 (0.1878)	0.3136	0.0179	0.13 (0.0201)	0.0381
10 [3] (8.28)	1	0.1786	1.55 (0.2703)	0.4489	0.1232	1.03 (0.1802)	0.3034	0.0175	0.11 (0.0194)	0.0369
	2	0.1856	1.65 (0.2872)	0.4728	0.01284	1.11 (0.1935)	0.3219	0.0190	0.12 (0.0274)	0.0407
	7	0.1878	1.67 (0.2913)	0.4792	0.1299	1.13 (0.1965)	0.3264	0.0192	0.13 (0.0221)	0.0413

[1]H: height of wall, B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

[3]fixed base width dose not fit static FOS.

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Table C7. Cumulative displacements for walls 4 to 10m high with B1-F7 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.54)	1	0.1469	3.63 (0.2535)	0.4004	0.1021	2.37 (0.1656)	0.2677	0.0098	0.16 (0.0113)	0.0211
	2	0.1521	3.83 (0.2671)	0.4192	0.1058	2.53 (0.1763)	0.2821	0.0105	0.18 (0.0124)	0.0230
	7	0.1543	3.89 (0.2717)	0.4260	0.1073	2.57 (0.1796)	0.2869	0.0107	0.18 (0.0127)	0.0234
5 (3.29)	1	0.1597	3.17 (0.2769)	0.4365	0.1111	2.08 (0.1819)	0.2930	0.0118	0.16 (0.0137)	0.0255
	2	0.1651	3.34 (0.2911)	0.4562	0.1159	2.21 (0.1932)	0.3091	0.0127	0.17 (0.0151)	0.0278
	7	0.1675	3.39 (0.2960)	0.4635	0.1176	2.25 (0.1967)	0.3143	0.0129	0.18 (0.0154)	0.0283
6 (4.05)	1	0.1705	2.85 (0.3983)	0.4688	0.1190	1.89 (0.1975)	0.3165	0.0140	0.15 (0.0161)	0.0301
	2	0.1763	2.99 (0.3128)	0.4891	0.1231	2.00 (0.2094)	0.3325	0.0149	0.17 (0.0179)	0.0328
	7	0.1787	3.04 (0.3181)	0.4968	0.1249	2.04 (0.2131)	0.3380	0.0151	0.17 (0.0183)	0.0334
7 (4.81)	1	0.1795	2.60 (0.3174)	0.4970	0.1251	1.74 (0.2120)	0.3371	0.0157	0.15 (0.0188)	0.0346
	2	0.1851	2.72 (0.3322)	0.5173	0.1288	1.83 (0.2242)	0.3529	0.0167	0.17 (0.0208)	0.0375
	7	0.1876	2.76 (0.3377)	0.5253	0.1311	1.86 (0.2276)	0.3587	0.0169	0.17 (0.0212)	0.0381
8 (5.57)	1	0.1871	2.40 (0.3346)	0.5217	0.1299	1.61 (0.2253)	0.351	0.0172	0.15 (0.0215)	0.0387
	2	0.1928	2.50 (0.3492)	0.5420	0.1345	1.70 (0.2367)	0.3712	0.0181	0.17 (0.0237)	0.0418
	7	0.1954	2.54 (0.3549)	0.5503	0.1363	1.72 (0.2408)	0.3771	0.0184	0.17 (0.0241)	0.0425
9 (6.43)	1	0.1925	2.17 (0.3410)	0.5335	0.1337	1.47 (0.2301)	0.3638	0.0183	0.15 (0.0233)	0.0417
	2	0.1981	2.26 (0.3555)	0.5537	0.1377	1.54 (0.2420)	0.3797	0.0193	0.16 (0.0256)	0.0449
	7	0.2007	2.30 (0.3612)	0.5620	0.1395	1.57 (0.2461)	0.3856	0.0195	0.17 (0.0261)	0.0456
10 (7.08)	1	0.1997	2.08 (0.3648)	0.5635	0.1386	1.42 (0.2475)	0.3846	0.0196	0.15 (0.0267)	0.0463
	2	0.2053	2.16 (0.3780)	0.5833	0.1420	1.49 (0.2595)	0.4015	0.0209	0.17 (0.0289)	0.0498
	7	0.2079	2.20 (0.3841)	0.5920	0.1440	1.51 (0.2638)	0.4078	0.0211	0.17 (0.0294)	0.0506

[1]H: height of wall, B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge= 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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Table C8. Cumulative displacements for walls 4 to 10m high with B2-F1 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	Rocking degree (m)	Total m	Northridge[2] Sliding m	Rocking degree (m)	Total m	Loma-Prieta[2] Sliding m	Rocking degree (m)	Total m
4 (1.73)	1	0.0936	3.40 (0.2376)	0.3312	0.0648	2.28 (0.1591)	0.2239	0.0056	0.16 (0.0113)	0.0169
	2	0.0979	3.58 (0.2503)	0.3482	0.0680	2.41 (0.1684)	0.2364	0.0061	0.18 (0.0123)	0.0184
	7	0.1021	3.75 (0.2618)	0.3639	0.0708	2.53 (0.1763)	0.2472	0.0064	0.19 (0.0130)	0.0194
5 (2.29)	1	0.1081	3.05 (0.2665)	0.3745	0.0745	2.03 (0.1776)	0.2520	0.0071	0.15 (0.0132)	0.0203
	2	0.1123	3.23 (0.2816)	0.3939	0.0777	2.16 (0.1886)	0.2663	0.0076	0.18 (0.0146)	0.0222
	7	01166	3.37 (0.2944)	0.4110	0.0809	2.26 (0.1976)	0.2785	0.0079	0.18 (0.0153)	0.0233
6 (2.85)	1	0.1194	2.83 (0.2957)	0.4151	0.0826	1.88 (0.1971)	0.2797	0.0084	0.15 (0.0159)	0.0243
	2	0.1239	2.98 (0.3120)	0.4359	0.0861	2.00 (0.2090)	0.2951	0.0090	0.17 (0.0175)	0.0265
	7	0.1286	3.11 (0.3260)	0.4546	0.0894	2.09 (0.2189)	0.3083	0.0094	0.18 (0.0184)	0.0278
7 (3.41)	1	0.1292	2.65 (0.3232)	0.4525	0.0895	1.77 (0.2160)	0.3055	0.0097	0.15 (0.0184)	0.0282
	2	0.1338	2.79 (0.3406)	0.4743	0.0930	1.87 (0.2286)	0.3216	0.0103	0.17 (0.0203)	0.0306
	7	0.1387	2.91 (0.3558)	0.4945	0.0964	1.96 (0.2393)	0.3358	0.0109	0.17 (0.0213)	0.0322
8 (3.97)	1	0.1375	2.50 (0.3491)	0.4867	0.0956	1.68 (0.2341)	0.3297	0.0110	0.15 (0.0211)	0.0321
	2	0.1422	2.63 (0.3670)	0.5092	0.0989	1.77 (0.2476)	0.3465	0.0118	0.17 (0.0231)	0.0349
	7	0.1474	2.74 (0.3833)	0.5307	0.1027	1.85 (0.2589)	0.3616	0.0123	0.17 (0.0243)	0.0366
9 (4.52)	1	0.1452	2.38 (0.3733)	0.5185	0.1008	1.60 (0.2510)	0.3518	0.0122	0.15 (0.0237)	0.0360
	2	0.1498	2.49 (0.3918)	0.5416	0.1049	1.69 (0.2647)	0.3696	0.0132	0.17 (0.0260)	0.0392
	7	0.1556	2.61 (0.4094)	0.5649	0.1087	1.76 (0.2769)	0.3856	0.0137	0.17 (0.0273)	0.0410
10 (5.08)	1	0.1520	2.27 (0.3960)	0.5480	0.1061	1.53 (0.2668)	0.3728	0.0135	0.15 (0.0265)	0.0399
	2	0.1569	2.38 (0.4150)	0.5720	0.1098	1.61 (0.2810)	0.3908	0.0143	0.17 (0.0289)	0.0433
	7	0.1625	2.48 (0.4333)	0.5957	0.1137	1.68 (0.2939)	0.4076	0.0151	0.17 (0.0303)	0.0454

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)= 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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Table C9. Cumulative displacements for walls 4 to 10m high with B2-F2 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	Rocking degree (m)	Total m	Northridge[2] Sliding m	Rocking degree (m)	Total m	Loma-Prieta[2] Sliding m	Rocking degree (m)	Total m
4 (1.95)	1	0.1033	3.18 (0.2223)	0.3256	0.0710	2.11 (0.1475)	0.2186	0.0066	0.16 (0.0109)	0.0175
	2	0.1075	3.37 (0.2350)	0.3425	0.0741	2.24 (0.1567)	0.2308	0.0071	0.17 (0.0118)	0.0188
	7	0.1115	3.51 (0.2451)	0.3565	0.0769	2.35 (0.1637)	0.2407	0.0074	0.18 (0.0124)	0.0194
5 (2.44)	1	0.1195	3.15 (0.2749)	0.3944	0.0828	2.11 (0.1838)	0.2666	0.0084	0.17 (0.0148)	0.0232
	2	0.1238	3.31 (0.2890)	0.4128	0.0862	2.22 (0.1941)	0.2802	0.0090	0.19 (0.0162)	0.0252
	7	0.1283	3.45 (0.3014)	0.4297	0.0893	2.32 (0.2028)	0.2921	0.0093	0.20 (0.0170)	0.0264
6 (3.13)	1	0.1294	2.74 (0.2865)	0.4159	0.0896	1.82 (0.1906)	0.2802	0.0097	0.15 (0.0160)	0.0257
	2	0.1340	2.88 (0.3017)	0.4357	0.0928	1.93 (0.2020)	0.2948	0.0104	0.17 (0.0177)	0.0281
	7	0.1387	3.00 (0.3146)	0.4533	0.0964	2.01 (0.2108)	0.3072	0.0108	0.18 (0.0185)	0.0293
7 (3.62)	1	0.1409	2.70 (0.3302)	0.4711	0.0979	1.82 (0.2220)	0.3199	0.0114	0.17 (0.0202)	0.0316
	2	0.1457	2.83 (0.3463)	0.4920	0.1013	1.91 (0.2338)	0.3351	0.0122	0.18 (0.0220)	0.0342
	7	0.1508	2.96 (0.3611)	0.5119	0.1058	2.00 (0.038)	0.3496	0.0127	0.19 (0.0232)	0.0359
8 (4.30)	1	0.1482	2.44 (0.3412)	0.4894	0.1028	1.64 (0.2290)	0.3319	0.0126	0.16 (0.0217)	0.0344
	2	0.1532	2.56 (0.3580)	0.5112	0.1069	1.73 (0.2414)	0.3483	0.0135	0.17 (0.0237)	0.0372
	7	0.1585	2.67 (0.3731)	0.5316	0.1111	1.80 (0.2516)	0.3628	0.0140	0.18 (0.0249)	0.0389
9 (4.80)	1	0.1575	2.41 (0.3785)	0.5360	0.1101	1.63 (0.2554)	0.3656	0.0141	0.16 (0.0258)	0.0399
	2	0.1621	2.52 (0.3955)	0.5576	0.1133	1.71 (0.2685)	0.3818	0.0152	0.18 (0.0281)	0.0433
	7	0.1676	2.62 (0.4122)	0.5798	0.1172	1.78 (0.2803)	0.3975	0.0158	0.19 (0.0294)	0.0452
10 (5.39)	1	0.1641	2.29 (0.3997)	0.5638	0.1145	1.55 (0.2709)	0.3854	0.0156	0.16 (0.0286)	0.0442
	2	0.1688	2.39 (0.4168)	0.5856	0.1178	1.63 (0.2839)	0.4018	0.0164	0.18 (0.0311)	0.0475
	7	0.1744	2.49 (0.4343)	0.6087	0.1219	1.70 (0.2962)	0.4181	0.0170	0.19 (0.0326)	0.0496

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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Table C10. Cumulative displacements for walls 4 to 10m high with B2-F3 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (1.94)	1	0.0956	2.92 (0.2039)	0.2994	0.0657	1.89 (0.1322)	0.1979	0.0053	0.12 (0.0084)	0.0137
	2	0.1006	3.09 (0.2156)	0.3163	0.0691	2.02 (0.1412)	0.2103	0.0057	0.13 (0.0092)	0.0150
	7	0.1048	3.23 (0.2253)	0.3301	0.0721	2.12 (0.1479)	0.2200	0.0060	0.14 (0.0097)	0.0157
5 (2.56)	1	0.1102	2.63 (0.2292)	0.3394	0.0752	1.70 (0.1487)	0.2239	0.0067	0.11 (0.0100)	0.0167
	2	01152	2.79 (0.2439)	0.3561	0.0793	1.82 (0.1590)	0.2383	0.0073	0.13 (0.0111)	0.0184
	7	01196	2.92 (0.2550)	0.3746	0.0823	1.91 (0.1668)	0.2492	0.0076	0.13 (0.0116)	0.0193
6 (3.17)	1	01219	2.44 (0.2556)	0.3775	0.0836	1.59 (0.1660)	0.2496	0.0081	0.12 (0.0121)	0.0202
	2	0.1269	2.59 (0.2709)	0.3978	0.0878	1.69 (0.1773)	0.2651	0.0087	0.13 (0.0134)	0.0221
	7	0.1316	2.70 (0.2832)	0.4148	0.0911	1.78 (0.1859)	0.2770	0.0090	0.13 (0.0141)	0.0231
7 (3.78)	1	0.1317	2.29 (0.2800)	0.4117	0.0909	1.50 (0.1828)	0.2737	0.0093	0.12 (0.0145)	0.0238
	2	0.1367	2.43 (0.2963)	0.4329	0.0944	1.60 (0.1952)	0.2895	0.0101	0.13 (0.0159)	0.0260
	7	0.1416	2.53 (0.3095)	0.4511	0.0982	1.67 (0.2041)	0.3023	0.0105	0.14 (0.0167)	0.0271
8 (4.39)	1	0.1401	2.17 (0.3028)	0.4429	0.0969	1.42 (0.1987)	0.2956	0.0106	0.12 (0.0166)	0.0272
	2	0.1451	2.19 (0.3196)	0.4646	0.1007	1.52 (0.2117)	0.3123	0.0113	0.13 (0.0182)	0.0295
	7	0.1502	2.39 (0.3336)	0.4839	0.1043	1.59 (0.2215)	0.3258	0.0117	0.14 (0.0191)	0.0308
9 (5.00)	1	0.1474	2.06 (0.3239)	0.4713	0.1021	1.36 (0.2141)	0.3162	0.0117	0.12 (0.0188)	0.0305
	2	0.1527	2.17 (0.3412)	0.4934	0.1058	1.45 (0.2271)	0.3329	0.0127	0.13 (0.0205)	0.0332
	7	0.1580	2.67 (0.3561)	0.5141	0.1095	1.51 (0.2375)	0.3470	0.0131	0.14 (0.0215)	0.0346
10 (5.61)	1	0.1543	1.97 (0.3437)	0.4980	0.1067	1.31 (0.2282)	0.3349	0.0130	0.12 (0.0209)	0.0340
	2	0.1597	2.07 (0.3614)	0.5210	0.1116	1.38 (0.2409)	0.3525	0.0139	0.13 (0.0229)	0.0369
	7	0.1653	2.16 (0.3769)	0.5422	0.1155	1.44 (0.2519)	0.3674	0.0144	0.14 (0.0240)	0.0385

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)= 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339

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Table C11. Cumulative displacements for walls 4 to 10m high with B2-F4 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (2.13)	1	0.1041	2.83 (0.1978)	0.3019	0.0709	1.83 (0.1279)	0.1989	0.0061	0.12 (0.0084)	0.0145
	2	0.1093	3.02 (0.2105)	0.3198	0.0749	1.96 (0.1369)	0.2119	0.0066	0.13 (0.0092)	0.0158
	7	0.1133	3.15 (0.2198)	0.3330	0.0778	2.05 (0.1433)	0.2211	0.0069	0.14 (0.0096)	0.0165
5 (2.76)	1	0.1187	2.61 (0.2277)	0.3645	0.0814	1.69 (0.1474)	0.2288	0.0077	0.12 (0.0105)	0.0183
	2	0.1237	2.77 (0.2420)	0.3657	0.0850	1.81 (0.1580)	0.2430	0.0083	0.13 (0.0117)	0.0200
	7	0.1281	2.89 (0.2525)	0.3806	0.0883	1.89 (0.1653)	0.2535	0.0087	0.14 (0.0123)	0.0209
6 (3.39)	1	0.1305	2.44 (0.256)	0.3861	0.0900	1.59 (0.1665)	0.2565	0.0092	0.12 (0.0129)	0.0221
	2	01355	2.59 (0.2709)	0.4064	0.0936	1.70 (0.1780)	0.2716	0.0099	0.14 (0.0142)	0.0241
	7	0.1402	2.70 (0.2826)	0.4228	0.0972	1.77 (0.1859)	0.2831	0.0103	0.14 (0.0149)	0.0252
7 (3.92)	1	0.1419	2.41 (0.2945)	0.4363	0.0982	1.59 (0.1941)	0.2924	0.0107	0.13 (0.0161)	0.0269
	2	0.1468	2.54 (0.3103)	0.4571	0.1021	1.69 (0.2062)	0.3084	0.0115	0.15 (0.0178)	0.0292
	7	0.1519	2.65 (0.3235)	0.4754	0.1057	1.76 (0.2155)	0.3212	0.0120	0.15 (0.0186)	0.0305
8 (4.65)	1	0.1488	2.18 (0.3049)	0.4533	0.1032	1.44 (0.2012)	0.3044	0.0119	0.13 (0.0175)	0.0294
	2	0.1541	2.30 (0.3210)	0.4751	0.1067	1.53 (0.2137)	0.3204	0.0128	0.14 (0.0193)	0.0321
	7	0.1593	2.40 (0.3345)	0.4938	0.1113	1.60 (0.2228)	0.3341	0.0133	0.14 (0.0202)	0.0335
9 (5.29)	1	0.1565	2.08 (0.3262)	0.4827	0.1090	1.38 (0.2163)	0.3254	0.0133	0.13 (0.0200)	0.0332
	2	0.1621	2.18 (0.3430)	0.5051	0.1131	1.46 (0.2291)	0.3422	0.0142	0.14 (0.0219)	0.0361
	7	0.1675	2.27 (0.3573)	0.5248	0.1169	1.52 (0.2391)	0.3561	0.0149	0.15 (0.0228)	0.0377
10 (5.82)	1	0.1648	2.04 (0.3563)	0.5211	0.1149	1.37 (0.2382)	0.3531	0.0148	0.13 (0.0232)	0.0380
	2	0.1699	2.14 (0.3731)	0.5430	0.1183	1.44 (0.2515)	0.3698	0.0158	0.15 (0.0254)	0.0412
	7	0.1755	2.23 (0.3886)	0.5641	0.1226	1.50 (0.2621)	0.3847	0.0164	0.15 (0.0266)	0.0430

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm)= 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339

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Table C12. Cumulative displacements for walls 4 to 10m high with B2-F5 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.33)	1	0.1132	2.82 (0.1966)	0.3098	0.0775	1.81 (0.1264)	0.2039	0.0072	0.12 (0.0087)	0.0158
	2	0.1183	3.01 (0.2102)	0.3285	0.0813	1.96 (0.1365)	0.2178	0.0078	0.14 (0.0097)	0.0175
	7	0.1224	3.13 (0.2188)	0.3412	0.0842	2.04 (0.1425)	0.2267	0.0081	0.15 (0.0102)	0.0183
5 (2.99)	1	0.1276	2.62 (0.2290)	0.3566	0.0880	1.70 (0.1485)	0.2365	0.0089	0.13 (0.0112)	0.0201
	2	0.1329	2.79 (0.2439)	0.3768	0.0917	1.83 (0.1598)	0.2515	0.0096	0.14 (0.0125)	0.0221
	7	0.1374	2.91 (0.2538)	0.3911	0.0949	1.91 (0.1667)	0.2615	0.0100	0.15 (0.0131)	0.0231
6 (3.74)	1	0.1376	2.15 (0.2458)	0.3834	0.0946	1.53 (0.1600)	0.2546	0.0102	0.12 (0.0129)	0.0231
	2	0.1432	2.50 (0.2613)	0.4045	0.0990	1.64 (0.1717)	0.2707	0.0110	0.14 (0.0144)	0.0254
	7	0.1478	2.60 (0.2719)	0.4197	0.1026	1.71 (0.1789)	0.2815	0.0115	0.14 (0.1490)	0.0264
7 (4.40)	1	0.1479	2.24 (0.2731)	0.4210	0.1023	1.47 (0.1793)	0.2817	0.0118	0.13 (0.0155)	0.0273
	2	0.1535	2.37 (0.2893)	0.4428	0.1070	1.57 (0.1914)	0.2984	0.0129	0.14 (0.0171)	0.0300
	7	0.1588	2.46 (0.3010)	0.4597	0.1105	1.63 (0.1995)	0.3100	0.0134	0.15 (0.0178)	0.0313
8 (5.06)	1	0.1570	2.13 (0.2978)	0.4548	0.1090	1.41 (0.1969)	0.3058	0.0135	0.13 (0.0180)	0.0315
	2	0.1626	2.25 (0.3143)	0.4769	0.1133	1.50 (0.2096)	0.3229	0.0145	0.14 (0.0200)	0.0345
	7	0.1678	2.34 (0.3267)	0.4945	0.1170	1.56 (0.2183)	0.3354	0.0152	0.15 (0.0208)	0.0360
9 (5.71)	1	0.1646	2.04 (0.3199)	0.4846	0.1146	1.36 (0.2131)	0.3277	0.0151	0.13 (0.0206)	0.0357
	2	0.1702	2.14 (0.3366)	0.5068	0.1187	1.44 (0.2260)	0.3447	0.0159	0.15 (0.0229)	0.0388
	7	0.1756	2.23 (0.3497)	0.5253	0.1225	1.50 (0.2353)	0.3578	0.0165	0.15 (0.0239)	0.0404
10 (6.37)	1	0.1714	1.95 (0.3399)	0.5113	0.1193	1.31 (0.2278)	0.3472	0.0162	0.13 (0.0233)	0.0395
	2	0.1768	2.04 (0.3566)	0.5335	0.1229	1.38 (0.2412)	0.3641	0.0171	0.15 (0.0258)	0.0429
	7	0.1824	2.12 (0.3704)	0.5528	0.1268	1.44 (0.2510)	0.3778	0.0176	0.15 (0.0269)	0.0445

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = .344*300 (mm) =   0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339

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Table C13. Cumulative displacements for walls 4 to 10m high with B2-F6 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.45)	1	0.1313	3.27 (0.2280)	0.3592	0.0907	2.15 (0.1501)	0.2408	0.0094	0.17 (0.0117)	0.0212
	2	0.1368	3.48 (0.2426)	0.3794	0.0949	2.31 (0.1610)	0.2559	0.0102	0.19 (0.0131)	0.0233
	7	0.1411	3.60 (0.2517)	0.3929	0.0980	2.40 (0.1674)	0.2653	0.0106	0.20 (0.0137)	0.0242
5 (3.29)	1	0.1425	2.75 (0.2403)	0.3827	0.0987	1.81 (0.1577)	0.2565	0.0111	0.15 (0.0131)	0.0241
	2	0.1487	2.93 (0.2561)	0.4047	0.1038	1.94 (0.1696)	0.2734	0.0121	0.17 (0.0147)	0.0268
	7	0.1532	3.04 (0.2656)	0.4188	0.1070	2.02 (0.1763)	0.2883	0.0125	0.18 (0.0153)	0.0279
6 (4.23)	1	0.1509	2.33 (0.2444)	0.3953	0.1047	1.53 (0.1598)	0.2645	0.0128	0.13 (0.0138)	0.0266
	2	0.1573	2.49 (0.2608)	0.4181	0.1096	1.65 (0.1725)	0.2821	0.0138	0.15 (0.0158)	0.0296
	7	0.1619	2.58 (0.2703)	0.4322	0.1129	1.71 (0.1792)	0.2921	0.0143	0.16 (0.0164)	0.0307
7 (5.07)	1	0.1593	2.13 (0.2597)	0.4191	0.1107	1.40 (0.1711)	0.2818	0.0142	0.13 (0.0161)	0.0301
	2	0.1658	2.26 (0.2764)	0.4422	0.1155	1.56 (0.1842)	0.2997	0.0154	0.15 (0.0181)	0.0334
	7	0.1707	2.34 (0.2862)	0.4568	0.1189	1.30 (0.1911)	0.3100	0.0158	0.15 (0.0188)	0.0346
8 (5.91)	1	0.1666	1.96 (0.2739)	0.4405	0.1155	1.40 (0.1819)	0.2975	0.0156	0.13 (0.0180)	0.0357
	2	0.1731	2.08 (0.2907)	0.4638	0.1202	1.45 (0.1953)	0.3154	0.0166	0.15 (0.2040)	0.0370
	7	0.1780	2.15 (0.3008)	0.4789	0.1236	1.22 (0.2024)	0.3261	0.0171	0.15 (0.0212)	0.0383
9 (6.75)	1	0.1730	1.83 (0.2870)	0.4599	0.1199	1.30 (0.1919)	0.3118	0.0167	0.13 (0.0201)	0.0368
	2	0.1796	1.93 (0.3035)	0.4831	0.1247	1.35 (0.2049)	0.3296	0.0178	0.14 (0.0226)	0.0404
	7	0.1847	2.00 (0.3139)	0.4986	0.1282	1.35 (0.2123)	0.3406	0.0183	0.15 (0.0235)	0.0417
10 (7.59)	1	0.1788	1.71 (0.2987)	0.4775	0.1234	1.15 (0.2013)	0.3247	0.0178	0.13 (0.0222)	0.0399
	2	0.1852	1.81 (0.3153)	0.5005	0.1282	1.23 (0.2143)	0.3425	0.0191	0.14 (0.0246)	0.0427
	7	0.1904	1.87 (0.3260)	0.5164	0.1321	1.27 (0.2216)	0.3537	0.0197	0.15 (0.0254)	0.0452

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339

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Table C14. Cumulative displacements for walls 4 to 10m high with B2-F7 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (2.24)	1	0.1485	4.28 (0.2984)	0.4469	0.1040	2.87 (0.2005)	0.3045	0.0103	0.21 (0.0146)	0.0249
	2	0.1529	4.46 (0.3110)	0.4640	0.1079	3.01 (0.2105)	0.3184	0.0108	0.23 (0.0159)	0.0268
	7	0.1581	4.63 (0.3234)	0.4815	0.1117	3.14 (0.2195)	0.3312	0.0113	0.24 (0.0167)	0.0280
5 (2.92)	1	0.1612	3.69 (0.3223)	0.4835	0.1135	2.49 (0.2173)	0.3308	0.0123	0.20 (0.0173)	0.0296
	2	0.1659	3.85 (0.3357)	0.5016	0.1170	2.61 (0.2281)	0.3451	0.0132	0.22 (0.0190)	0.0322
	7	0.1718	4.00 (0.3490)	0.5208	0.1209	2.72 (0.2377)	0.3586	0.0137	0.23 (0.0198)	0.0336
6 (3.61)	1	0.1721	3.29 (0.3445)	0.5166	0.1205	2.23 (0.2334)	0.3539	0.0144	0.19 (0.0202)	0.0346
	2	0.1770	3.42 (0.3584)	0.5354	0.1243	2.33 (0.2443)	0.3686	0.0154	0.21 (0.0221)	0.0375
	7	0.1827	3.56 (0.3725)	0.5552	0.1284	2.43 (0.2544)	0.3828	0.0159	0.22 (0.0232)	0.0391
7 (4.29)	1	0.1808	2.98 (0.3646)	0.5454	0.1267	2.03 (0.2479)	0.3746	0.0162	0.19 (0.0233)	0.0394
	2	0.1859	3.10 (0.3785)	0.5644	0.1302	2.12 (0.2592)	0.3894	0.0169	0.21 (0.0255)	0.0424
	7	0.1917	3.22 (0.3932)	0.5850	0.1344	2.21 (0.2698)	0.4041	0.0176	0.22 (0.0265)	0.0441
8 (4.97)	1	0.1884	2.74 (0.3825)	0.5709	0.1317	1.87 (0.2613)	0.3930	0.0176	0.19 (0.0263)	0.0438
	2	0.1933	2.84 (0.3964)	0.5898	0.1348	1.95 (0.2728)	0.4077	0.0183	0.20 (0.0286)	0.0470
	7	0.1994	2.95 (0.4117)	0.6111	0.1391	2.03 (0.2838)	0.4229	0.0189	0.21 (0.0299)	0.0488
9 (5.66)	1	0.1949	2.54 (0.3987)	0.5936	0.1357	1.74 (0.2737)	0.4094	0.0187	0.19 (0.0292)	0.0480
	2	0.1999	2.63 (0.4123)	0.6122	0.1387	1.82 (0.2851)	0.4238	0.0198	0.20 (0.0315)	0.0513
	7	0.2060	2.73 (0.4281)	0.6342	0.1437	1.88 (0.2959)	0.4395	0.0206	0.21 (0.0327)	0.0533
10 (6.34)	1	0.2007	2.37 (0.4131)	0.6138	0.1391	1.63 (0.2849)	0.4240	0.0202	0.18 (0.0318)	0.0520
	2	0.2056	2.44 (0.4267)	0.6323	0.1429	1.69 (0.2957)	0.4386	0.0211	0.20 (0.0343)	0.0554
	7	0.2118	2.54 (0.4429)	0.6547	0.1473	1.76 (0.3074)	0.4547	0.0218	0.20 (0.0357)	0.0575

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes according to Eurocode = 300×αmax

El-Centro = 0.349*300 (mm)= 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta= 0.113*300 (mm) = 0.0339m

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Table C15. Cumulative displacements for walls 4 to 10m high with B3-F1 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (1.54)	1	0.0875	3.68 (0.2566)	0.3441	0.0611	2.50 (0.1747)	0.2358	0.0054	0.19 (0.0130)	0.0184
	2	0.0909	3.85 (0.2686)	0.3595	0.0634	2.62 (0.1832)	0.2466	0.0059	0.20 (0.142)	0.0201
	7	0.0996	4.27 (0.2979)	0.3975	0.0695	2.92 (0.2040)	0.2735	0.0066	0.23 (0.0161)	0.0227
5 (1.90)	1	0.1029	3.70 (0.3231)	0.4261	0.0720	2.54 (0.2215)	0.2935	0.0072	0.21 (0.0184)	0.0256
	2	0.1062	3.85 (0.3363)	0.4425	0.0743	2.65 (0.2312)	0.3055	0.0076	0.23 (0.0199)	0.0275
	7	0.1163	4.28 (0.3733)	0.4896	0.0813	2.95 (0.2574)	0.3387	0.0084	0.26 (0.0227)	0.0311
6 (2.27)	1	0.1156	3.65 (0.3825)	0.4981	0.0808	2.52 (0.2635)	0.3443	0.0087	0.23 (0.0241)	0.0328
	2	0.1189	3.79 (0.3966)	0.5155	0.0831	2.62 (0.2742)	0.3573	0.0094	0.25 (0.0258)	0.0352
	7	0.1302	4.21 (0.4405)	0.5707	0.0918	2.91 (03051)	0.3969	0.0104	0.28 (0.0294)	0.0398
7 (2.73)	1	0.1250	3.37 (0.4113)	0.5363	0.0881	2.32 (0.2883)	0.3714	0.0101	0.22 (0.0272)	0.0373
	2	0.1285	3.49 (0.4262)	0.5547	0.0908	2.41 (02946)	0.3853	0.0107	0.24 (0.0294)	0.0402
	7	0.1404	3.8 (0.4735)	0.6139	0.0993	2.69 (0.3282)	0.4275	0.0120	0.27 (0.0334)	0.0454
8 (3.19)	1	0.1333	3.14 (0.4388)	0.5721	0.0940	2.17 (0.3025)	0.3964	0.0114	0.22 (0.0307)	0.0420
	2	0.1369	3.26 (0.4545)	0.5914	0.0964	2.25 (0.3145)	0.4108	0.0121	0.24 (0.0330)	0.0451
	7	0.1497	3.62 (0.5053)	0.6550	0.1052	2.51 (0.3502)	0.4554	0.0135	0.27 (0.0374)	0.0509
9 (3.65)	1	0.1408	2.96 (0.4646)	0.6054	0.0987	2.04 (0.3207)	0.4195	0.0127	0.22 (0.0340)	0.0467
	2	0.1446	3.06 (0.4810)	0.6256	0.1011	2.12 (0.3330)	0.4341	0.0135	0.23 (0.0366)	0.0500
	7	0.1576	3.40 (0.5343)	0.6919	0.1105	2.36 (0.3705)	0.4809	0.0148	0.26 (0.0414)	0.0562
10 (4.11)	1	0.1473	2.80 (0.4887)	0.6360	0.1028	1.94 (0.3377)	0.4406	0.0139	0.21 (0.0374)	0.0513
	2	0.1510	2.89 (0.5052)	0.6562	0.1055	2.01 (0.3500)	0.4554	0.0144	0.23 (0.0401)	0.0546
	7	0.1644	3.21 (0.5610)	0.7254	0.1149	2.23 (0.3893)	0.5042	0.0159	0.26 (0.0420)	0.0611

[1]H: height of wall,   B: base width
[2]Permissible displacements for three Earthquakes

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge = 0.344*300 (mm) = 0.1032m
Loma-Prieta = 0.113*300 (mm) = 0.0339m

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Table C16. Cumulative displacements for walls 4 to 10m high with B3-F2 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (1.74)	1	0.0967	3.45 (0.2411)	0.3378	0.0670	2.33 (0.1627)	0.2297	0.0063	0.18 (0.0123)	0.0186
	2	0.1001	3.62 (0.2526)	0.3527	0.0696	2.45 (0.1711)	0.2407	0.0067	0.19 (0.0134)	0.0201
	7	0.1091	3.99 (0.2787)	0.3877	0.0759	2.71 (0.1895)	0.2654	0.0074	0.22 (0.0151)	0.0226
5 (2.13)	1	0.1125	3.51 (0.3061)	0.4186	0.0785	2.39 (0.2087)	0.2872	0.0081	0.21 (0.0179)	0.0261
	2	0.1160	3.65 (0.3187)	0.4347	0.0810	2.50 (0.2178)	0.2989	0.0087	0.22 (0.0195)	0.0282
	7	0.1263	4.03 (0.3520)	0.4784	0.0883	2.77 (02413)	0.3296	0.0097	0.25 (0.0220)	0.0316
6 (2.52)	1	0.1254	3.47 (0.3639)	0.4893	0.0876	2.39 (0.2500)	0.3376	0.0100	0.22 (0.0236)	0.0336
	2	0.1289	3.60 (0.3772)	0.5061	0.0908	2.48 (0.2598)	0.3506	0.0106	0.24 (0.0256)	0.0362
	7	0.1404	3.98 (0.4170)	0.5574	0.0993	2.75 (0.2878)	0.3871	0.0118	0.27 (0.0288)	0.0406
7 (2.90)	1	0.1366	3.40 (0.4155)	0.5521	0.0962	2.35 (02870)	0.3832	0.0119	0.24 (0.0295)	0.0414
	2	0.1403	3.52 (0.4298)	0.5701	0.0985	2.44 (0.2970)	0.3961	0.0126	0.26 (0.0316)	0.0442
	7	0.1527	3.89 (0.4756)	0.6283	0.1073	2.70 (0.3300)	0.4373	0.0141	0.29 (0.0357)	0.0498
8 (3.39)	1	0.1451	3.17 (0.4421)	0.5873	0.1017	2.19 (0.3057)	0.4074	0.0134	0.24 (0.0330)	0.0464
	2	0.1488	3.27 (0.4567)	0.6055	0.1042	2.27 (0.3164)	0.4206	0.0140	0.25 (0.0354)	0.0494
	7	0.1618	3.62 (0.5054)	0.6672	0.1133	2.51 (0.3508)	0.4641	0.0154	0.29 (0.0398)	0.0552
9 (3.87)	1	0.1525	2.97 (0.4666)	0.6191	0.1066	2.06 (0.3228)	0.4294	0.0145	0.23 (0.0365)	0.0510
	2	0.1561	3.06 (0.4814)	0.6375	0.1089	2.13 (0.3339)	0.4428	0.0151	0.25 (00389)	0.0541
	7	0.1695	3.39 (0.5326)	0.7021	0.1188	2.35 (0.3697)	0.4885	0.0166	0.28 (0.0437)	0.0603
10 (4.46)	1	0.1579	2.71 (0.4731)	0.6310	0.1101	1.87 (0.3270)	0.4371	0.0154	0.22 (0.0379)	0.0533
	2	0.1616	2.80 (0.4882)	0.6497	0.1129	1.94 (0.3381)	0.4510	0.0160	0.23 (0.0405)	0.0564
	7	0.1751	3.09 (0.5397)	0.7148	0.1224	2.15 (0.3744)	0.4969	0.0174	0.26 (0.0453)	0.0627

[1]H: height of wall, B: base width
[2]Permissible displacements for three Earthquakes

El-Centro = 0.349*300 (mm) = 0.1047m
Northridge= 0.344*300 (mm) =0.1032m
Loma-Prieta= 0.113*300 (mm)=0.0339m

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Table C17. Cumulative displacements for walls 4 to 10m high with B3-F3 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	Cumulative Displacement								
		El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (1.82)	1	0.0882	2.91 (0.2031)	0.2913	0.0605	1.91 (0.1332)	0.1937	0.0051	0.13 (0.0089)	0.0140
	2	0.0925	3.07 (0.2140)	0.3065	0.0637	2.02 (0.1413)	0.2050	0.0052	0.13 (0.0093)	0.0145
	7	0.1012	3.40 (0.2375)	0.3387	0.0698	2.26 (0.1580)	0.2277	0.0057	0.15 (0.0105)	0.0162
5 (2.22)	1	0.1049	3.00 (0.2615)	0.3665	0.0726	1.99 (0.1740)	0.2467	0.0065	0.14 (0.0123)	0.0189
	2	0.1088	3.15 (0.2745)	0.3833	0.0753	2.11 (0.1837)	0.2591	0.0070	0.15 (0.0135)	0.0205
	7	0.1189	3.49 (0.3049)	0.4238	0.0830	2.35 (0.2050)	0.2881	0.0078	0.17 (0.0152)	0.0230
6 (2.63)	1	0.1181	3.00 (0.3143)	0.4324	0.0822	2.02 (0.2118)	0.2940	0.0081	0.16 (0.0167)	0.0248
	2	0.1218	3.13 (0.3282)	0.4500	0.0850	212 (0.2221)	0.3071	0.0086	0.17 (0.0181)	0.0267
	7	0.1330	3.48 (0.3645)	0.4975	0.0929	2.37 (0.2477)	0.3406	0.0096	0.20 (0.0206)	0.0302
7 (3.03)	1	0.1290	2.96 (0.3615)	0.4905	0.0899	2.01 (0.2456)	0.3355	0.0096	0.17 (0.0212)	0.0309
	2	0.1327	3.08 (0.3759)	0.5086	0.0927	2.10 (0.2566)	0.3493	0.0103	0.19 (0.0230)	0.0332
	7	0.1448	3.42 (0.4175)	0.5622	0.1025	2.34 (0.2856)	0.3880	0.0115	0.21 (0.0259)	0.0374
8 (3.54)	1	0.1370	2.76 (0.3857)	0.5227	0.0963	1.88 (0.2625)	0.3588	0.0110	0.17 (0.0240)	0.0350
	2	0.1408	2.87 (0.4005)	0.5413	0.0994	1.96 (0.2739)	0.3732	0.0115	0.19 (0.0259)	0.0374
	7	0.1536	3.19 (0.4449)	0.5985	0.1084	2.19 (0.3053)	0.4137	0.0129	0.21 (0.0291)	0.0421
9 (4.04)	1	0.1443	2.60 (0.4084)	0.5527	0.1015	1.77 (0.2786)	0.3801	0.0122	0.17 (0.0268)	0.0390
	2	0.1482	2.70 (0.4236)	0.5718	0.1041	1.85 (0.2906)	0.3946	0.0129	0.18 (0.0289)	0.0418
	7	0.1616	2.99 (0.4704)	0.6321	0.1133	2.06 (0.3235)	0.4368	0.0143	0.21 (0.0326)	0.0469
10 (4.54)	1	0.1510	2.46 (0.4298)	0.5808	0.1056	1.68 (0.2939)	0.3995	0.0133	0.17 (0.0296)	0.0429
	2	0.1550	2.55 (0.4453)	0.6003	0.1085	1.75 (0.3057)	0.4142	0.0142	0.18 (0.0319)	0.0461
	7	0.1685	2.83 (0.4939)	0.6624	0.1180	1.95 (0.3401)	0.4581	0.0156	0.21 (0.0359)	0.0515

[1]H: height of wall, B: base width
[2]Permissible displacements for three Earthquakes

El-Centro=0.349*300 (mm)=0.1047m
Northridge=0.344*300 (mm)= 0.1032
Loma-Prieta=0.113*300 (mm) =0.033

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Table C18. Cumulative displacements for walls 4 to 10m high with B3-F4 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.09)	1	0.0943	2.59 (0.1808)	0.2751	0.0642	1.67 (0.1164)	0.1806	0.0055	0.11 (0.0077)	0.0132
	2	0.0987	2.75 (0.1922)	0.2909	0.0673	1.79 (0.1248)	0.1922	0.0059	0.12 (0.0083)	0.0142
	7	0.1076	3.04 (0.2124)	0.3200	0.0739	1.99 (0.1386)	0.2125	0.0065	0.13 (0.0093)	0.0157
5 (2.51)	1	0.1113	2.74 (0.2395)	0.3509	0.0769	1.81 (0.1576)	0.2343	0.0073	0.13 (0.0116)	0.0189
	2	0.1156	2.89 (0.2526)	0.3681	0.0802	1.92 (0.1673)	0.2475	0.0078	0.15 (0.0127)	0.0205
	7	01256	3.20 (0.2760)	0.4046	0.0872	2.13 (0.1859)	0.2731	0.0086	0.16 (0.0142)	0.0228
6 (2.92)	1	0.1247	2.79 (0.2926)	0.4173	0.0868	1.87 (0.1955)	0.2823	0.0089	0.15 (0.0160)	0.0249
	2	0.1289	2.92 (0.3063)	0.4352	0.0896	1.97 (0.2060)	0.2956	0.0096	0.17 (0.0173)	0.0269
	7	0.1400	3.23 (0.3384)	0.4784	0.0977	2.18 (0.2283)	0.3260	0.0106	0.19 (0.0195)	0.0301
7 (3.35)	1	0.1359	2.78 (0.3398)	0.4757	0.0948	1.88 (0.2299)	0.3247	0.0106	0.17 (0.0205)	0.0311
	2	0.1399	2.90 (0.3540)	0.4939	0.0987	1.97 (0.2403)	0.3390	0.0114	0.18 (0.0221)	0.0335
	7	0.1519	3.20 (0.3911)	0.5430	0.1073	2.18 (0.2668)	0.3741	0.0215	0.20 (0.0248)	0.0373
8 (3.77)	1	0.1457	2.74 (0.3823)	0.5280	0.1025	1.87 (0.2606)	0.3631	0.0124	0.18 (0.0250)	0.0374
	2	0.1500	2.84 (0.3970)	0.5471	0.1051	1.95 (0.2720)	0.3771	0.0131	0.19 (0.0270)	0.0401
	7	0.1628	3.14 (0.4390)	0.6018	0.1144	2.16 (0.3015)	0.4159	0.0147	0.22 (0.0303)	0.0449
9 (4.19)	1	0.1544	2.68 (0.4209)	0.5754	0.1083	1.84 (0.2886)	0.3969	0.0140	0.19 (0.0296)	0.0436
	2	0.1584	2.77 (0.4356)	0.5941	0.1108	1.91 (0.3001)	0.4109	0.0147	0.20 (0.0319)	0.0466
	7	0.1718	3.07 (0.4817)	0.6536	0.1203	2.12 (0.3327)	0.4259	0.0160	0.23 (0.0358)	0.0519
10 (4.72)	1	0.1608	2.53 (0.4411)	0.6017	0.1123	1.74 (0.3033)	0.4156	0.0151	0.19 (0.0326)	0.0477
	2	0.1648	2.61 (0.4559)	0.6207	0.1153	1.80 (0.3144)	0.4297	0.0157	0.20 (0.0350)	0.0507
	7	0.1785	2.89 (0.5039)	0.6825	0.1250	2.00 (0.3484)	0.4734	0.0172	0.22 (0.0392)	0.0564

[1]H: height of wall, B: base width
[2]Permissible displacements for three earthquakes

El-Centro =0.349*300 (mm)=0.1047m
Northridge =0.344*300 (mm)=0.1032r
Loma-Prieta=0.113*300 (mm)   =0.03

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Table C19. Cumulative displacements for walls 4 to 10m high with B3-F5 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2]			Northridge[2]			Loma-Prieta[2]		
		Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m	Sliding m	Rocking degree (m)	Total m
4 (2.27)	1	0.1035	2.62 (0.1829)	0.2863	0.0706	1.68 (0.1176)	0.1882	0.065	0.12 (0.0081)	0.0146
	2	0.1082	2.80 (0.1954)	0.3036	0.0742	182 (0.1267)	0.2009	0.0071	0.13 (0.0091)	0.0161
	7	0.1170	3.07 (0.2144)	0.3314	0.0805	2.00 (0.1399)	0.2204	0.0077	0.14 (0.0101)	0.0178
5 (2.71)	1	0.1202	2.77 (0.2414)	0.3616	0.0832	1.82 (0.1591)	0.2423	0.0085	0.14 (0.0124)	0.0210
	2	0.1248	2.92 (0.2550)	0.3798	0.0866	1.94 (0.1692)	0.2559	0.0091	0.16 (0.0137)	0.0229
	7	0.1349	3.21 (0.2800)	0.4150	0.0937	2.14 (0.1869)	0.2806	0.0100	0.18 (0.0153)	0.0253
6 (3.16)	1	0.1337	2.80 (0.2934)	0.4271	0.0931	1.88 (0.1967)	0.2898	0.0103	0.16 (0.0170)	0.0273
	2	0.1380	2.94 (0.3076)	0.4456	0.0969	1.98 (0.2073)	0.3042	0.0111	0.18 (0.0186)	0.0297
	7	0.1492	3.23 (0.3380)	0.4872	0.1053	2.18 (0.2237)	0.3390	0.0121	0.20 (0.0207)	0.0328
7 (3.60)	1	0.1450	2.78 (0.3398)	0.4847	0.1019	1.88 (0.2302)	0.3322	0.0123	0.18 (0.0217)	0.0340
	2	0.1497	2.90 (0.3545)	0.5042	0.1048	1.98 (0.2417)	0.3466	0.0131	0.19 (0.0236)	0.0367
	7	0.1619	3.19 (0.3900)	0.5519	0.1134	2.18 (0.2668)	0.3802	0.0145	0.22 (0.0263)	0.0408
8 (4.14)	1	0.1538	2.63 (0.3673)	0.5211	0.1074	1.79 (0.2503)	0.3577	0.0141	0.18 (0.0250)	0.0389
	2	0.1582	2.74 (0.3821)	0.5404	0.1106	1.87 (0.2617)	0.3723	0.0147	0.20 (0.0273)	0.0419
	7	0.1709	3.01 (0.4202)	0.5911	0.1195	2.07 (0.2887)	0.4082	0.0159	0.22 (0.0305)	0.0464
9 (4.68)	1	0.1611	2.49 (0.3918)	0.5529	0.1125	1.71 (0.2681)	0.3805	0.0151	0.18 (0.0285)	0.0436
	2	0.1656	2.59 (0.4067)	0.5722	0.1157	1.78 (0.2794)	0.3951	0.0159	0.20 (0.0308)	0.0467
	7	0.1786	2.85 (0.4471)	0.6258	0.1250	1.96 (0.3081)	0.4330	0.0172	0.22 (0.0343)	0.0516
10 (5.23)	1	0.1676	2.37 (0.4138)	0.5813	0.1170	1.63 (0.2840)	0.4009	0.0162	0.18 (0.0317)	0.0479
	2	0.1720	2.46 (0.4287)	0.6007	0.1197	1.69 (0.2958)	0.4155	0.0169	0.20 (0.0342)	0.0511
	7	0.1854	2.70 (0.4712)	0.6566	0.1295	1.87 (0.3256)	0.4551	0.0183	0.22 (0.0380)	0.0563

[1]H: height of wall,   B: base width
[2]Permissible displacements for three earthquakes

El-Centro=0.349*300 (mm)=0.1047m
Northridge=0.344*300 (mm)=   0.1032
Loma-Prieta=0.113*300 (mm) =0.033

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Table C20. Cumulative displacements for walls 4 to 10m high with B3-F6 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 [3] (3.34)	1	0.1037	1.65 (0.1155)	0.2192	0.0692	0.99 (0.0690)	0.1382	0.0071	0.07 (0.0500)	0.0121
	2	0.1109	1.84 (0.1285)	0.2395	0.0744	1.12 (0.0785)	0.1529	0.0078	0.08 (0.0058)	0.0136
	7	0.1182	1.99 (0.1388)	0.2569	0.0797	1.22 (0.0854)	0.1650	0.0084	0.09 (0.0063)	0.0146
5 (3.95)	1	0.1206	1.79 (0.1565)	0.2771	0.0818	1.12 (0.0975)	0.1793	0.0090	0.09 (0.0077)	0.0167
	2	0.1272	1.96 (0.1711)	0.2983	0.0867	1.24 (0.1085)	0.1952	0.0099	0.10 (0.0088)	0.0187
	7	0.1356	2.12 (0.1848)	0.3204	0.0930	1.35 (0.1178)	0.2107	0.0107	0.11 (0.0095)	0.0202
6 (4.56)	1	0.1340	1.85 (0.1936)	0.3276	0.0917	1.18 (0.1240)	0.2159	0.0109	0.10 (0.0106)	0.0215
	2	0.1406	2.00 (0.2090)	0.3496	0.0964	1.30 (0.1359)	0.2323	0.0121	0.11 (0.0120)	0.0241
	7	0.1500	2.16 (0.2259)	0.3759	0.1037	1.41 (0.1473)	0.2510	0.0129	0.12 (0.0131)	0.0260
7 (5.27)	1	0.1441	1.80 (0.2198)	0.3639	0.0994	1.17 (0.1429)	0.2423	0.0127	0.11 (0.0131)	0.0258
	2	0.1505	1.93 (0.2353)	0.3858	0.1043	1.27 (0.1550)	0.2592	0.0138	0.12 (0.0149)	0.0287
	7	0.1605	2.08 (0.2543)	0.4148	0.1114	1.38 (0.1683)	0.2797	0.0148	0.13 (0.0162)	0.0310
8 (5.88)	1	0.1536	1.79 (0.2495)	0.4031	0.1064	1.18 (0.1648)	0.2712	0.0143	0.12 (0.0163)	0.0306
	2	0.1598	1.90 (0.2651)	0.4249	0.1108	1.27 (0.1773)	0.2881	0.0153	0.13 (0.184)	0.0337
	7	0.1703	2.05 (0.2867)	0.4571	0.1182	1.38 (0.1925)	0.3108	0.0164	0.14 (0.0201)	0.0365
9 (6.49)	1	0.1617	1.76 (0.2761)	0.4379	0.1121	1.18 (0.1848)	0.2969	0.0157	0.12 (0.0196)	0.0353
	2	0.1679	1.86 (0.2916)	0.4594	0.1160	1.26 (0.1974)	0.3134	0.0166	0.14 (0.0219)	0.0385
	7	0.1790	2.01 (0.3155)	0.4944	0.1243	1.36 (0.2139)	0.3382	0.0178	0.15 (0.0239)	0.0416
10 (7.00)	1	0.1698	1.76 (0.3065)	0.4763	0.1177	1.19 (0.2074)	0.3251	0.0170	0.13 (0.0234)	0.0404
	2	0.1755	1.85 (0.3220)	0.4975	0.1218	1.26 (0.2197)	0.3415	0.0183	0.15 (0.0257)	0.0440
	7	0.1873	2.00 (0.3486)	0.5359	0.1299	1.37 (0.2387)	0.3686	0.0195	0.16 (0.0281)	0.0476

[1]H: height of wall, B: base width
[2]Permissible displacements for three earthquakes

El-Centro =0.349*300 (mm)= 0.1047m
Northridge=0.344*300 (mm)= 0.1032m
Loma-Prieta=0.113*300(mm)=0.0339m

[3]fixed base width dose not fit static FOS.

Table C21. Cumulative displacements for walls 4 to 10m high with B3-F7 and field conditions 1, 2 and 7 (Table 4.2) subjected to El-Centro, Northridge and Loma-Prieta earthquakes.

H and B[1] (m)	Field Con.	El-Centro[2] Sliding m	El-Centro[2] Rocking degree (m)	El-Centro[2] Total m	Northridge[2] Sliding m	Northridge[2] Rocking degree (m)	Northridge[2] Total m	Loma-Prieta[2] Sliding m	Loma-Prieta[2] Rocking degree (m)	Loma-Prieta[2] Total m
4 (1.76)	1	0.1450	5.45 (0.3803)	0.5253	0.1027	3.83 (0.2672)	0.3698	0.0109	0.33 (0.0228)	0.0337
	2	0.1482	5.59 (0.3903)	0.5386	0.1052	3.94 (0.2751)	0.3803	0.0114	0.35 (0.0244)	0.0358
	7	0.1608	6.14 (0.4284)	0.5892	0.1141	4.34 (0.3028)	0.4109	0.0127	0.39 (0.0274)	0.0401
5 (2.32)	1	0.1581	4.63 (0.4040)	0.5621	0.1115	3.24 (0.2827)	0.3942	0.0129	0.30 (0.0260)	0.0389
	2	0.1617	4.76 (0.4151)	0.5768	0.1140	3.34 (0.2914)	0.4054	0.0137	0.32 (0.0280)	0.0417
	7	0.1752	5.23 (0.4560)	0.6312	0.1235	3.68 (0.3210)	0.4445	0.0151	0.36 (0.0314)	0.0465
6 (2.89)	1	0.1685	4.07 (0.4267)	0.5952	0.1184	2.85 (0.2983)	0.4167	0.0148	0.28 (0.0296)	0.0444
	2	0.1723	4.18 (0.4382)	0.6105	0.1207	2.94 (0.3076)	0.4283	0.0154	0.30 (0.0317)	0.0471
	7	0.1863	4.60 (0.4815)	0.6678	0.1311	3.23 (0.3384)	0.4695	0.0168	0.34 (0.0355)	0.0523
7 (3.45)	1	0.1771	3.66 (0.4474)	0.6244	0.1237	2.56 (0.3131)	0.4369	0.0162	0.27 (0.0332)	0.0494
	2	0.1809	3.76 (0.4591)	0.6400	0.1266	2.64 (0.3222)	0.4488	0.0168	0.29 (0.0353)	0.0522
	7	0.1954	4.13 (0.5043)	0.6997	0.1369	2.90 (0.3548)	0.4916	0.0184	0.32 (0.0393)	0.0577
8 (4.02)	1	0.1844	3.34 (0.4660)	0.6504	0.1287	2.34 (0.3263)	0.4550	0.0174	0.26(0.0365)	0.0540
	2	0.1882	3.42 (0.4777)	0.6659	0.1312	2.41 (0.3358)	0.4670	0.0184	0.28 (.0386)	0.570
	7	0.2030	3.76 (0.5248)	0.7277	0.1415	2.65 (0.3697)	0.5112	0.0202	0.31 (0.0430)	0.0632
9 (4.68)	1	0.1894	2.98 (0.4687)	0.6581	0.1319	2.09 (0.3280)	0.4600	0.0189	0.24 (0.0379)	0.568
	2	0.1935	3.06 (0.4804)	0.6739	0.1343	2.15 (0.3377)	0.4720	0.0196	0.26 (0.0403)	0.0599
	7	0.2082	3.36 (0.5273)	0.7355	0.1447	2.36 (0.3714)	0.5160	0.0212	0.28 (0.0447)	0.0659
10 (5.14)	1	0.1962	2.85 (0.4980)	0.6941	0.1359	2.01 (0.3501)	0.4860	0.0201	0.25 (0.0428)	0.0629
	2	0.2000	2.92 (0.5095)	0.7094	0.1382	2.06 (0.3594)	0.4976	0.0208	0.26 (0.0453)	0.0661
	7	0.2151	3.21 (0.5594)	0.7745	0.1488	2.26 (0.3952)	0.5440	0.0225	0.29 (0.0502)	0.0726

[1]H: height of wall, B: base width
[2]Permissible displacements for three earthquakes

El-Centro =0.349*300 (mm)=0.1047m
Northridge=0.344*300 (mm)= 0.103
Loma-Prieta=0.113*300 (mm) =0.03

PERMISSIBLE DISPLACEMENT

3 QUESTIONS ???

1. Is the permissible displacement related to height of wall?

2. Is the permissible displacement related to design acceleration?

3. Is the permissible displacement a fixed number irrespective of the wall height?

PERFORMANCE BASED DESIGN.

- Determine the section for static loading condition with FOS=2.5 in bearing, and FOS= 1.5 for sliding and tilting as a rigid body and no tension on the heel.
- Estimate the sliding displacement from Wu's (1999). Design charts for comparable, backfill and foundation soils, and comparable ground motion.
- Compare these displacements with permissible displacements as per Euro Code ($300 \times \alpha_{max}$).
- If displacement in 2 is less than that in 3, then designs is OK, or else revise the sections of the wall for lower FOS in (1).

EUROCODE-8 CH.7
(OLDER VERSION)

1. Based on psuedo-static analysis.
2. Wall movements for gravity structures include sliding and rocking.
3. Included non-linear behavior in base soil and backfill.
4. Effect of dry, saturated pervious, impervious and submerged backfill are included.
5. The point of application of the dynamic earth increment is at mid-height of the wall.
6. **Hydro dynamic forces at the back and front of the wall=7/12*k_h*γ_w*H'^2, point of acting is at the 0.4 from the base of the saturated layer.**
7. Permissible displacement (d) d=300 x α_{max} (mm) α_{max} is maximum acceleration ratio

EUROCODE – 8 CHAPTER 7
(NEWER VERSION)

EARTH RETAINING STRUCTURES
1) Permanent displacements, in the form of combined sliding and tilting may be acceptable.
2) The following aspects should properly be accounted for:
   1) Non-linear behavior
   2) Inertial effects
   3) Hydrodynamic effects behind the wall and/or the outer face of the wall
3) The intensity of such equivalent seismic forces depends, for a given seismic zone, on the amount of <u>permanent displacement which is both acceptable and actually permitted</u> by the adopted structural solution.
4) The Point of application of dynamic earth pressures at mid-height of the wall. For walls free to rotate about their toe, the dynamic force acts the same point as the static force. For the soil under the water table, a distinction shall be made between pervious and impervious conditions.

COMMENTS

1. **Permissible Displacement**
   a. **Less than 300 a**
   b. **No Guidelines (new)**
2. Hydrodynamic Pressure
   a. Impervious Soils (one time)
   b. Pervious Soils (two times)
3. **Non-linear Analysis**

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CONCLUSIONS

1. **A rational method of analysis considering real ground motion, non-linear soil properties and different water conditions around free standing retaining walls has been developed.**
2. A wall with negative inclination is technically a sound proposition during earthquakes. It may stand 2-3 shocks before it becomes vertical and may prevent overturning.
3. **These walls will be economical in section to about 10% in the volume of the material.**
4. Field data on displacements of walls needs be used to validate this analysis further.

This analysis can be easily modified for abutments.

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SOLUTION FOR ABUTMENTS
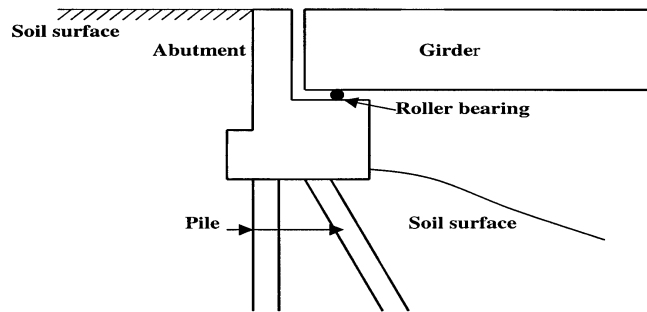
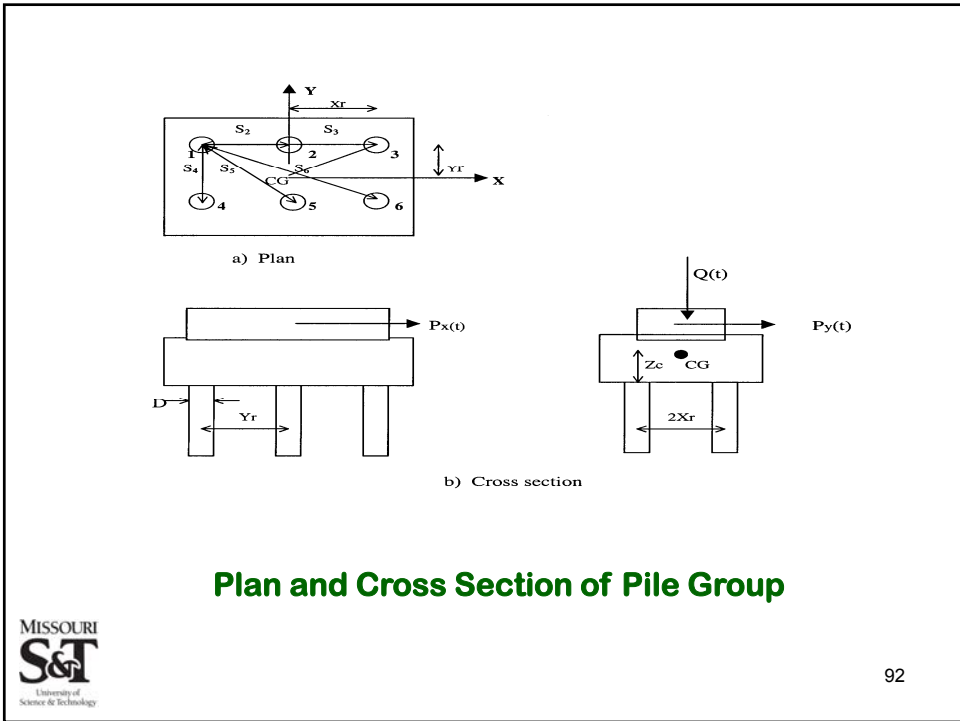**Typical Highway Bridge Abutment Supported on Piles**
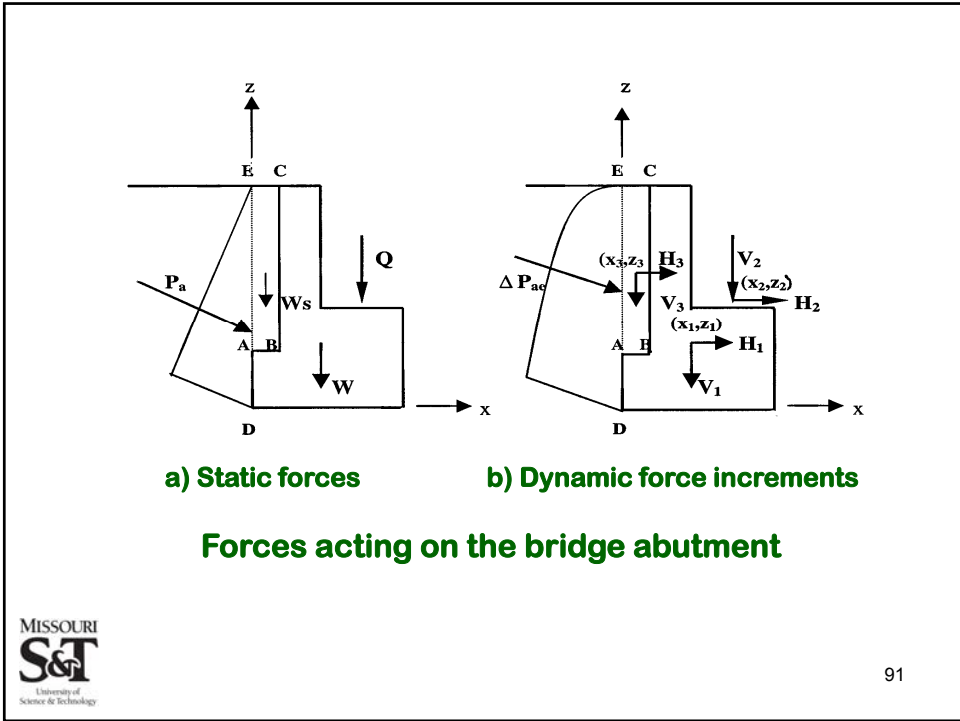
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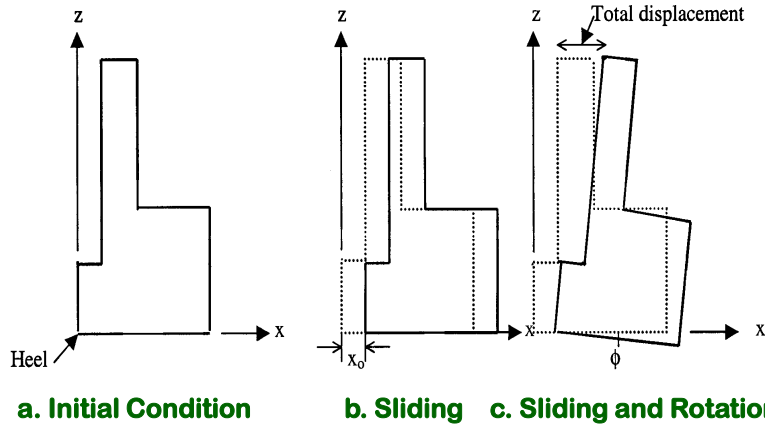
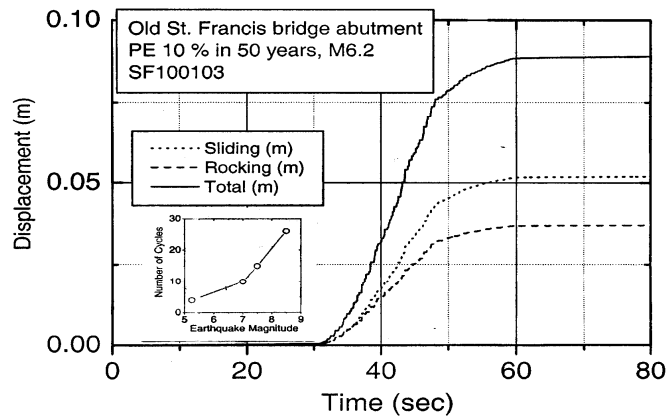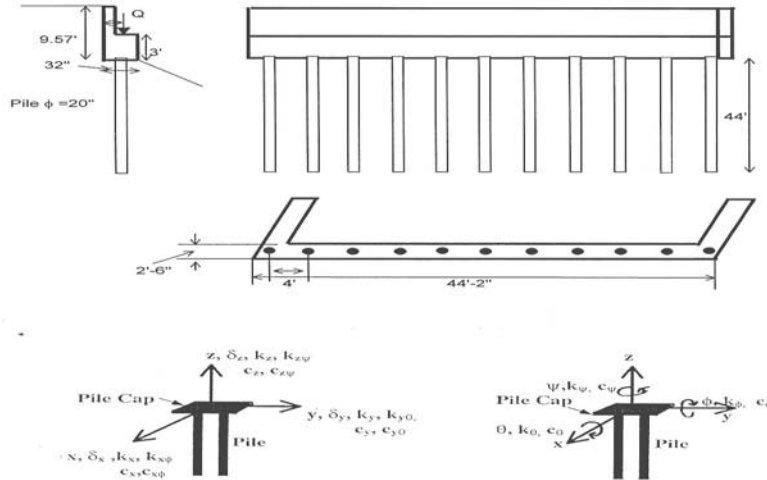**a. Initial Condition**   **b. Sliding**   **c. Sliding and Rotation**

Translations and Rotation Movement of Abutment

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a) Static forces   b) Dynamic force increments

Forces acting on the bridge abutment

a) Plan

b) Cross section

Plan and Cross Section of Pile Group

New-St. Francis Bridge Abutment

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Old St. Francis bridge abutment
PE 10 % in 50 years, M6.2
SF100103

Sliding (m)
Rocking (m)
Total (m)

Time Histories of Sliding, Rocking and Total Displacement Magnitude 6.2

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Time Histories of Sliding, Rocking and Total displacement Magnitude 7.2

95
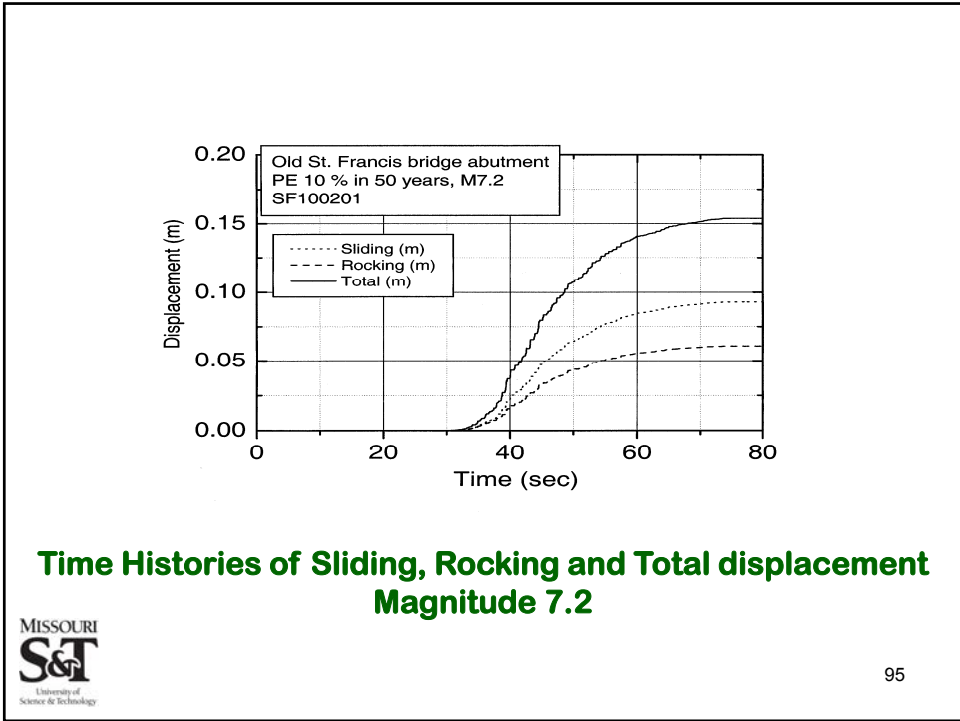
Displacement at top of abutment	PE 10% in 50 years		PE 2% in 50 years	
	M6.2	M7.2	M6.4	M8.0
Sliding (m)	0.052	0.093	0.096	0.31
Rocking (m)	0.037	0.061	0.069	0.21
Total (m)	0.089	0.154	0.165	0.52
Significant Cycles	8	11	9	20
Displacement in 1-cycle	0.011	0.014	0.018	0.026

Displacement at the Top of the Old St.Francis Bridge Abutment

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Displacement at top of abutment	PE 10% in 50 years		PE 2% in 50 years	
	M6.4	M7.0	M7.8	M8.0
Sliding (m)	0.037	0.028	0.139	0.178
Rocking (m)	0.018	0.053	0.0513	0.064
Total (m)	0.056	0.080	0.190	0.242
Significant Cycles	9	10	18	20
Displacement in 1-cycle	0.007	0.008	0.011	0.012

Displacement at the Top of the Old Wahite Ditch Bridge Abutment

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Thank You

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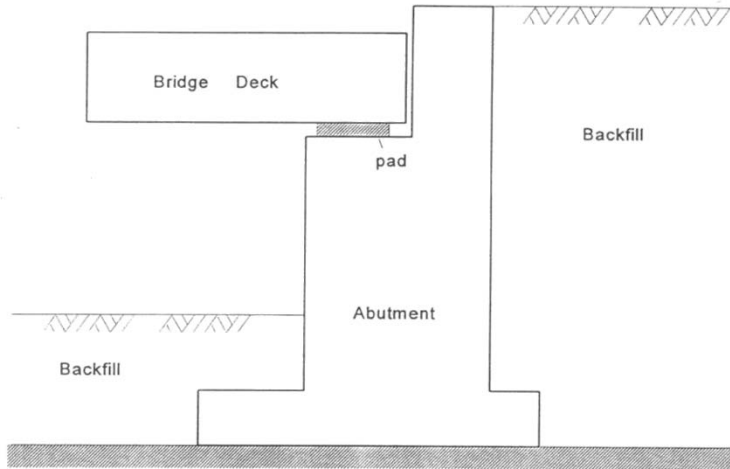
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BRIDGE ABUTMENT

Fig. Section of abutment (After Maragakis and Siddharthan, 1989)