

With the Same Amount of Wall, an Uneven Layout Twists the Floor and Moves the Soft Side Far More

— the soft-side wall carries a small force of **0.239130** yet moves more, and walls at right angles to the push pick up **0.260870** — the separator is whether one asks about amount or about layout — [Paper 855]

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Abstract

Against sideways forces on a building, the advice is “add more wall”. This paper counts that the answer changes with layout even when the amount is the same. No new theorem or law is claimed. First, where the force acts and where the walls resist are different points: the force acts at the centre of mass $x = 5$; the walls resist about the stiffness-weighted centre of rigidity (Section 2). Second, a balanced layout does not twist: with 2.0 and 2.0 the centres coincide and both sides move 0.25 (Section 2). Third, and this is the core. With the same amount, an uneven layout moves the soft side far more: **1.913043** times at 3.5 and 0.5, and **2.687927** times at 3.9 and 0.1 (Section 3). Fourth, the soft-side wall carries little force yet moves a lot: at 3.5 and 0.5 its force is 0.239130 and its displacement 0.478261 (Section 3). Fifth, walls at right angles to the push also work: with only a sideways force applied, the perpendicular walls pick up **0.260870** (Section 3). Sixth, the separator is whether one asks about amount or about layout: total stiffness is 4.0 in every layout; only placement changed (Section 4). **Keywords:** shear wall, centre of rigidity, eccentricity, torsion, layout, model.

Scope of this paper (scope note): No new theorem or law is claimed: that in a building with a rigid floor lateral force acts at the centre of mass while resistance is centred at the centre of rigidity, that their offset (eccentricity) causes torsion, that torsion enlarges displacement on the side far from the centre of rigidity, and that perpendicular walls also resist torsion, are all known.No design advice is given, where to place walls, required wall quantities and limits on eccentricity are not stated.No real building is claimed: a 10 m square plan and wall stiffnesses such as 2.0, 3.5 and 0.5 are model values.The floor is taken as rigid: floor flexibility is not included.Only a static one-directional force is considered: earthquake response, wall failure and reversal of the force are not included.Relation to earlier papers: Paper 840 showed that a tree has more than one “middle”, centre and centroid differing in over half of all trees. This paper stands beside it: here too there are two middles, and when the middle of force (centre of mass) and the middle of resistance (centre of rigidity) separate, the floor twists.Paper 300 showed that whether two things share a root is decidable: amount and layout are distinct roots by that criterion.What is added is laying out wall forces and displacements for three layouts at equal total stiffness, confirming force and moment equilibrium in each, measuring that the soft side carries less force yet moves more, and placing the separator on amount versus layout.

1. Notation and the Question

Setting: a 10 m square rigid floor rests on y -direction walls at $x = 0$ and $x = 10$ and x -direction walls at $y = 0$ and $y = 10$ (stiffness 2.0 each).A unit y -direction force acts at the centre of mass $x = 5$.

$$x_r = \frac{\sum_i k_i x_i}{\sum_i k_i}, \quad e = x_m - x_r, \quad \theta = \frac{F e}{J}, \quad u_i = \frac{F}{\sum_i k_i} + \theta (x_i - x_r)$$

x_r is the centre of rigidity, e the eccentricity, J the torsional stiffness and u_i the displacement of y -wall i .The total y -wall stiffness is held at 4.0 in every layout.

Question: with the same amount of wall, does layout not matter?

2. A Balanced Layout

Computation 2.1: with 2.0 and 2.0, wall forces and displacements were computed.

wall	force	displacement
$x = 0$ (stiffness 2.0)	0.500000	0.250000
$x = 10$ (stiffness 2.0)	0.500000	0.250000
perpendicular wall $y = 0$	0.000000	—

Observation 2.2

the centres coincide and the floor does not twist. Eccentricity is 0 and both sides move equally: the perpendicular walls carry no force.

3. Uneven Layouts

Computation 3.1: keeping total stiffness at 4.0, the sides were made uneven.

layout (left, right)	centre of rigidity	eccentricity	soft-side displacement	ratio to balanced
2.0, 2.0	5.0000	0.0000	0.250000	1.000000
3.5, 0.5	1.2500	3.7500	0.478261	1.913043
3.9, 0.1	0.2500	4.7500	0.671982	2.687927

Observation 3.2

this is the core. With the same amount, the soft side moves far more. 1.913043 times at 3.5 and 0.5, 2.687927 times at 3.9 and 0.1: the centre of rigidity moves toward the stiff side, and the force at the centre of mass turns the floor about it.

Computation 3.3: for 3.5 and 0.5, wall forces and displacements were computed.

wall	force	displacement
$x = 0$ (stiffness 3.5)	0.760870	0.217391
$x = 10$ (stiffness 0.5)	0.239130	0.478261
perpendicular wall $y = 0$	0.260870	—
perpendicular wall $y = 10$	−0.260870	—

Observation 3.4

the soft-side wall carries little force yet moves a lot. Its force 0.239130 is below the balanced 0.5, while its displacement 0.478261 is above 0.25: looking only at forces misses where the building moves most.

Observation 3.5

walls at right angles to the push also work. With only a y force applied, the x walls carry 0.260870 and -0.260870 : they are used as a pair to stop the floor from twisting.

Observation 3.6

equilibrium closes in every layout. Forces sum to the applied 1 with difference 0, and the residual moment about the centre of mass is below 10^{-15} , so the differing factors come from layout, not from an arithmetic slip.

4. The Separator

Observation 4.1

the separator is whether one asks about amount or about layout. Total stiffness is 4.0 in all three layouts, yet the soft-side displacement runs from 1.000000 to 2.687927 times: amount is fixed by the total; twisting is fixed by placement.

Observation 4.2

placed beside Paper 840.840 showed that a tree's "middle" is not one point, centre and centroid differing. Here too there are two middles, the middle of force (centre of mass) and the middle of resistance (centre of rigidity), and their separation twists the floor. In trees the two middles stayed neighbours; here the size of the separation becomes a factor on displacement. Paper 300 showed that whether two things share a root is decidable: amount and layout are distinct roots by that criterion.

Observation 4.3

what is not said. Where walls should go, required quantities, earthquake response and wall failure are not treated. What is shown is that with the amount held fixed, layout changes displacement.

5. Census and Closing

1. force at the centre of mass, resistance at the centre of rigidity (Section 1): **two middles**.
2. balanced: both sides move **0.25** (Computation 2.1): **no twist**.
3. **3.5, 0.5**: eccentricity **3.75** (Computation 3.1): **rigidity shifts**.
4. soft side **1.913043** times (Computation 3.1): **the core**.
5. **3.9, 0.1**: **2.687927** times (Computation 3.1): **more uneven**.
6. soft-side force **0.239130** (Computation 3.3): **small**.
7. its displacement **0.478261** (Computation 3.3): **large**.
8. perpendicular walls carry **0.260870** (Computation 3.3): **a pair against twist**.
9. equilibrium closes in each layout (Observation 3.6): **no arithmetic slip**.
10. amount, or layout (Observation 4.1): **the separator; Papers 840, 300**.

Closing: With the same amount of wall, an uneven layout twists the floor and moves the soft side far more. Keeping total stiffness at 4.0 while shifting from 2.0 and 2.0 to 3.5 and 0.5 moves the centre of rigidity to 1.25, an eccentricity of 3.75, and the soft side displaces 1.913043 times the balanced value, rising to 2.687927 at 3.9 and 0.1: the force acts at the centre of mass while the walls resist about a centre pulled toward the stiff side, so the floor turns. The soft-side wall then carries only 0.239130 yet moves 0.478261, and walls at right angles to the push pick up 0.260870: looking only at forces misses where the building moves most. Force and moment equilibrium close in every layout, so the differences come from placement. Placed among the earlier papers: beside Paper 840's "two middles", as the case where the separation of centre of mass and centre of rigidity becomes a factor on displacement, and treating amount and layout as distinct roots by the criterion of Paper 300. To be honest: the floor is rigid and only a static one-directional force is considered; earthquake response and wall failure are not included.

References

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