Distribute the torsion load

The torsional moment is created by the offset of the center of gravity (seismic force center) from the center of stiffness or resistance (also called the center of rigidity). For the N-S load direction, the torsional moment is equal to the total seismic shear load on the story multiplied by the x-coordinate offset of the center of gravity and the center of stiffness (i.e., 8,983 lb x 7 ft = 62,881 ft-lb). The sharing of this torsional moment on all of the shear wall lines is based on the torsional moment of resistance of each wall line. The torsional moment of resistance is determined by the design shear capacity of each wall line (used as the measure of relative stiffness) multiplied by the square of its distance from the center of stiffness. The amount of the torsional shear load (torsional moment) distributed to each wall line is then determined by the each wall's torsional moment of resistance in proportion to the total torsional moment of resistance of all shear wall lines combined. The torsional moment of resistance of each shear wall line and the total for all shear wall lines (torsional moment of inertia) is determined as shown below.

Wall Line	F_{psw}	Distance from Center of Resistance	$F_{psw}(d)^2$
PSW1	7,812 lb	19.3 ft	2.91 x 10^6 lb-ft^2
PSW2	3,046 lb	25.3 ft	1.95 x 10^6 lb-ft^2
PSW3	14,463 lb	12.1 ft	2.12 x 10^6 lb-ft^2
PSW4	9,453 lb	10.1 ft	9.64 x 10^5 lb-ft^2
PSW5	182 lb	44.7 ft	3.64 x 10^5 lb-ft^2
PSW6	9,453 lb	9.9 ft	9.26 x 10^5 lb-ft^2
PSW7	9,687 lb	22.7 ft	4.99 x 10^6 lb-ft^2
PSW8	11,015 lb	15.9 ft	2.78 x 10^6 lb-ft^2
Total torsional moment of inertia (*J*)			1.70 x 10^7 lb-ft^2

Now, the torsional shear load on each wall is determined using the following basic equation for torsion:

$$V_{WALL} = \frac{M_T d(F_{WALL})}{J}$$

where,

V_{WALL} = the torsional shear load on the wall line (lb)
M_T = the torsional moment* (lb-ft)
d = the distance of the wall from the center of stiffness (ft)
F_{WALL} = the design shear capacity of the segmented or perforated shear wall line (lb)
J = the torsional moment of inertia for the story (lb-ft^2)

*The torsional moment is determined by multiplying the design shear load on the story by the offset of the center of stiffness relative to the center of gravity perpendicular to the load direction under consideration. For wind design, the center of the vertical projected area of the building is used in lieu of the center gravity.

Now, the torsional loads may be determined as shown below for the N-S and E-W wall lines. For PSW1 and PSW2 the torsion load is in the reverse direction of the direct shear load on these walls. This behavior is the result of the center of shear resistance being offset from the force center which causes rotation about the center of stiffness. (Center of shear resistance and center of stiffness may be used interchangeably since the shear resistance is assumed to represent stiffness.) If the estimated offset of the center of gravity and the center of stiffness is reasonably correct, then the torsional response will tend to reduce the shear load on PSW1 and PSW2. However, codes generally do not allow the direct shear load on a wall line to be reduced due to torsion – only increases should be considered.

The following values for use in the torsion equation apply to this example:

M_T = (8,983 lb)(7 ft) = 62,881 ft-lb
J = 1.70 x 10^7 lb-ft^2

The torsional loads on PSW5 and PSW7 are determined as follows:

V_{psw5} = (62,881 ft-lb)(44.7 ft)(182 lb) / (1.70 x 10^7 lb-ft^2)
= 30 lb

V_{psw7} = (62,881 ft-lb)(22.7 ft)(9,687 lb) / (1.70 x 10^7 lb-ft^2)
= 813 lb

These torsional shear loads are added to the direct shear loads for the N-S walls and the total design shear load on each wall line may be compared to its design shear capacity as shown below.

N-S Wall Lines	Wall Design Capacity, F_{psw} (lb)	Direct Shear Load (lb)	Torsional Shear Load (lb)	Total Design Shear Load (lb)	Percent of Design Capacity Used
PSW1	7,812	3,387	na*	3,387	43% (ok)
PSW2	3,046	1,321	na*	1,321	43% (ok)
PSW5	182	81	30	111	61% (ok)
PSW7	9,687	4,195	813	5,008	52% (ok)

*The torsional shear load is actually in the reverse direction of the direct shear load for these walls, but it is not subtracted as required by code practice.

While all of the N-S shear wall lines have sufficient design capacity, it is noticeable that the wall lines on the left side (West) of the building are “working harder” and the walls on the right side (East) of the building are substantially over-designed. The wall construction could be changed to allow a greater sheathing nail spacing on walls PSW1 and PSW2. Also, the assumption of a rigid diaphragm over the entire expanse of the story is very questionable, even if the garage is “rigidly” tied to the house with adequate connections. It is likely that the loads on Walls PSW5 and PSW7 will be higher than predicted using the relative stiffness method. Thus, the tributary area method (see Step 2) may provide a more reliable design and should be considered along with the above analysis. Certainly, reducing the shear wall construction based on the above analysis is not recommended prior to “viewing” the design from the perspective of the tributary area approach. Similarly, the garage opening wall (PSW5) should not be assumed to be adequate simply based on the above analysis in view of the inherent assumptions of the relative stiffness method in the horizontal distribution of shear forces. For more compact buildings with continuous horizontal diaphragms extending over the entire area of each story, the method is less presumptive in nature. But, this qualitative observation is true of all of the force distribution methods demonstrated in this design example.