Understanding Substantial Structural Damage in the International Existing Building Code

This document will help you understand how the concept of Substantial Structural Damage (SSD) is used within the *International Existing Building Code®* (IEBC®). FEMA's Public Assistance Required Minimum Standards Policy found in the Public Assistance Program and Policy Guide, Chapter 2 – Section VII.B.2,[1] (Policy) requires that projects receiving FEMA assistance for repair or replacement incorporate the natural hazards-related provisions of the most recent edition of the International Code Council's® (ICC®) *International Building Code®* (IBC®), *International Residential Code®* (IRC®), and/or the IEBC. The policy applies to buildings that have sustained any level of damage (including, possibly, SSD or Substantial Damage), as well as projects involving new construction, such as improved projects[2], alternate projects[3], or projects eligible for replacement in accordance with 44 CFR, Part 206.226(f). The relevant code provisions include not only the design criteria for repair or replacement construction, but also those provisions that determine whether repair to the pre-damage condition is sufficient, or whether repair must be supplemented by improvement. One of those scope-determining provisions involves the concept of SSD.

Which Building Codes Include SSD Provisions?

- The IBC is a code for new construction. The 2015 edition of the IBC no longer contains provisions for existing buildings. Therefore, while the definition of SSD remains in IBC Chapter 2, the code does not cite it. Instead, IBC Section 101.4.7 refers the reader to the IEBC. Where the IEBC requires repairs that involve new members[4] or where it requires improvement (retrofit) in addition to repair, IBC provisions sometimes apply to the new work. IBC provisions also apply to new construction when FEMA policy allows replacement instead of repair.
- The IEBC is a code for regulating work on existing buildings. It contains provisions that assess damage, require repair, and sometimes trigger improvement. One condition that triggers improvement is Substantial Structural Damage. A feature of the IEBC is that it allows many conditions to remain in existing buildings that would no longer be allowed in similar new buildings. When improvement is required, the IEBC also sometimes allows less stringent criteria than the IBC. The IEBC applies to all building types and occupancies that, in new construction, would be regulated by the IBC. It can also be used for residential buildings that, in new construction, would be regulated by the IRC. (The IEBC provides three methods, only two of which use the concept of SSD; see Other Things to Know, below.)
- The IRC is primarily a code for new construction of one- and two-family dwellings and certain townhouses. Section R102.7.1 generally requires repair of damage, but the IRC does not use the concept of SSD to trigger improvement relative to the pre-damage condition. (Appendix J contains alternative provisions similar to those of the IEBC, but it is rarely adopted.) Thus, the IRC and the IEBC are different in how they treat damage and how they trigger improvements. (See Other Things to Know, below.)

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1 FEMA Public Assistance Program and Policy Guide FP 104-009-2, April 2017.

2 44 CFR § 206.203(d)(1)

3 44 CFR § 206.203(d)(2)

4 New members refer to new structural members or new building elements.

Since neither the IBC nor the IRC directly use the concept of SSD, this Job Aid considers application of the IEBC only. It applies to the repair provisions in either the IEBC's Prescriptive method (Section 404) or the IEBC's Work Area method (Chapter 6). (See Other Things to Know, below, for more about the IEBC's three methods.)

How SSD Relates to Repairs

The IEBC, at minimum, requires any damage to be repaired by restoring it to the pre-damage condition (Sections 404.1 or 601.1). In some cases, the code requires not only repair of the damage, but also improvement of the building beyond its pre-damage condition. With respect to natural hazards, the IEBC "triggers" such improvements when damage is classified as either Substantial Damage or Substantial Structural Damage.

- Substantial Damage (SD), defined in terms of repair cost, requires the entire structure to be retrofitted to meet the requirements for new flood-resistant construction (Section 404.5 or 606.2.4). The IEBC's SD provisions apply only in flood hazard areas.
- Substantial Structural Damage (SSD), defined in terms of capacity loss, requires evaluation and/or retrofit of certain structural elements other than the damaged elements, as explained further below.

It is possible for a building to sustain both SD and SSD in the same event, in which case both sets of requirements will apply. Even so, SSD is different from SD, despite the similar names. (See the Public Assistance Job Aid on *Understanding Substantial Damage in the International Building Code, International Existing Building Code, or International Residential Code* (https://www.fema.gov/media-library/assets/documents/130382) for more on Substantial Damage.

The IEBC defines SSD as follows:[5]

SUBSTANTIAL STRUCTURAL DAMAGE. *A condition where one or both of the following apply:*

1. *The vertical elements of the lateral force-resisting system have suffered damage such that the lateral load-carrying capacity of any story in any horizontal direction has been reduced by more than 33 percent from its predamage condition.*
2. *The capacity of any vertical component carrying gravity load, or any group of such components, that supports more than 30 percent of the total area of the structure's floor(s) and roof(s) has been reduced more than 20 percent from its predamage condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75 percent of that required by this code for new buildings of similar structure, purpose and location.*

The cause of the damage is irrelevant to the definition. However, if SSD is present, the criteria for the triggered retrofits, as well as some of the exceptions to the triggered scope, refer to specific types of loads or hazards.

Each of the two types of SSD triggers its own scope of improvement, and each requires its own design criteria:

- SSD to the lateral system (Type 1 in the definition) requires the entire lateral system – even the parts that sustained no damage – to be evaluated for certain wind and seismic loads and retrofitted as needed. One- and two-family dwellings are exempt from seismic work, as are buildings outside regions of high seismicity as long as the SSD was not caused by earthquake. (Sections 404.2 or 606.2.2)

[5] The definition reprinted here includes errata published by ICC on February 1, 2016.

- SSD to the gravity system (Type 2 in the definition) requires the damaged members, as well as those undamaged members supporting their loads, to be retrofitted to carry the dead and live loads (and snow, if the damage was caused by snow) required for new construction. (Sections 404.3 or 606.2.3)

In addition:

- SSD to the gravity system caused by wind or earthquake is to be treated like SSD to the lateral system (Sections 404.3.1 or 606.2.3.1). This is because such damage indicates that the building's lateral system was inadequate to protect the gravity system from a critical loss of capacity.

- The definition of SSD requires an assessment of capacity loss to the "vertical" elements or components. In the case of SSD to the gravity system, these are the columns or bearing walls, but not the floor framing or diaphragms. In the case of SSD to the lateral system, these are the walls or frames that characterize the system, but not the diaphragms or other load path components. Thus, one of the most common wind-induced structural damage modes – wind uplift of the roof deck or roof support structure – cannot be classified as SSD because the roof deck and framing are not considered vertical elements.

- While nonstructural damage can indicate structural damage, nonstructural damage does not count toward SSD. Even if SSD has occurred, nonstructural components are not required to be evaluated or retrofitted.

- Section 502.3 states that any work necessary to comply with the code's repair provisions is considered part of the repair and is not intended to trigger further requirements as an alteration[6] project. Though the provision is not as clear as it could be, this should be understood to mean that even a seismic, wind, or flood upgrade triggered by SD or SSD should not be classified or regulated as a voluntary alteration. (Technically, Section 502.3 applies only to the Work Area method, but the same idea, though unstated, should apply to the Prescriptive method as well.)

Making the SSD Determination

Because SSD is defined in terms of capacity loss to structural elements, making the SSD determination requires an understanding of the building's structural system, as well as the extent and meaning of the damage. Making the SSD determination requires two separate assessments, one for each type of SSD:

- For each story, in each direction, assess the reduction in lateral load-carrying capacity of the vertical structural elements of the lateral force-resisting system.

- For each damaged gravity load-carrying vertical element, or group of elements, assess the reduction in gravity load-carrying capacity.

Although the SSD definition includes specific values of capacity loss, the code provides no guidance for quantifying the loss and makes no requirements regarding the types of investigation or analysis that might be needed. Some documents have been developed to guide the assessment of damage,[7] but even these are not comprehensive with respect to structure types and damage sources. Therefore, different approaches and ample judgment are typically applied. In the absence of an objective standard, the code official,[8] retains the right to require or waive more thorough documentation, testing, analysis, or peer review depending on what the permit applicant is claiming.

[6] An "alteration" per the 2015 IEBC is defined as any construction or renovation to an existing structure other than a repair or addition.

[7] Examples include FEMA 306 which provides guidance on the evaluation of earthquake-damaged concrete and masonry walls and FEMA 352 which offers a methodology for assessing earthquake damage to welded steel moment frames.

[8] The IEBC defines and uses the term "code official" in essentially the same way that the IBC defines and uses "building official."

Where the damage is obviously minimal or obviously severe, a thorough knowledge of the structural system might not be necessary. Nevertheless, professionals making an SSD determination should understand that structural damage can sometimes be hidden, and that even visible damage can be misleading if the structural system is unknown.

By FEMA policy, a determination of whether SSD has occurred may be made by the code official, the recipient's or sub-recipient's registered design professional, or another qualified individual. FEMA may review the determination to ensure consistency with the IEBC requirements. If needed, FEMA may hire a technical assistance contractor to assist in these determinations.

Other Things to Know

- Substantial Structural Damage and Substantial Damage are two conditions in which the IEBC requires a building to be improved beyond its pre-damage condition. In addition, though separate from the IEBC, FEMA policy also allows improvement of a damaged building through replacement when the cost of repair would exceed 50 percent of the replacement cost.
- The IEBC allows the permit applicant to select one of three compliance methods. The IEBC sections cited in this Job Aid come from the Prescriptive method (Section 404) and the Work Area method (Chapter 6). The Performance method is rarely used to regulate repairs, and its provisions are not well maintained or consistently interpreted. FEMA interprets the IEBC as limiting the Performance method to relatively recent buildings, or buildings in which the pre-damage structural system already complies with IBC requirements for new construction. With this interpretation, there would never be a need to improve the structure even if SSD did occur. However, some jurisdictions have interpreted the Performance method to allow exemptions even to non-conforming buildings and never to require improvement even in the case of SSD. This interpretation is inconsistent with FEMA policy.
- As noted above, the IEBC can be applied to any structure type or occupancy, including one- and two-family dwellings. Some jurisdictions, however, allow the IRC, which does not include SSD provisions, to be used for existing dwellings. FEMA may require the use of the IEBC in these cases.

References

2015 International Existing Building Code. International Code Council, 2014.

2015 International Building Code. International Code Council, 2014.

2015 International Residential Code. International Code Council, 2014.

EXAMPLE — EARTHQUAKE DAMAGE

The following hypothetical example illustrates application of the IEBC's SSD provisions to earthquake damage.

Building Description

- Public middle school classroom building, with eight classrooms. If built new, the building would be assigned to Risk Category II or III, depending on whether the total occupant load exceeds 250.
- 2 stories above grade, about 9,000 gross square feet (GSF).
- Built in 1975.
- Gravity system: Steel floor and roof framing with a grid of steel tube columns.
- Lateral system: By default, lightly reinforced concrete masonry unit (CMU) partitions resisted lateral deformations but might not have been designed for seismic loading.
- Key nonstructural components: CMU partitions and pilasters between and around steel tube columns. Exterior brick veneer. Suspended panelized ceilings with integrated light fixtures.
- Not in a flood hazard area.
- Low seismicity. If built new, the building would be assigned to Seismic Design Category B.

Most of the building attributes – its age, size, quality of design or construction, even the local seismicity – are immaterial to the determination of SSD. The most important information involves the gravity and lateral structural systems, as they affect one's understanding of the observed damage.

Damage Description

- CMU partitions: Stepped cracking within mortar joints (Figures 1 and 2), typical in both stories, both directions. Vertical cracks adjacent to encased steel columns. Horizontal separation between CMU units in multiple locations, up to one-inch wide in four places in the north-south direction in the second story (Figure 2). Crushed, spalled or buckled masonry units (Figure 1) in four locations in the first story, at the toe of north-south wall segments.
- Steel floor/roof framing and tube columns: No apparent damage. The frame clearly swayed, but with damaged CMU removed in a few locations (Figure 3), no member buckling, weld damage, or bolt damage was observed, and none is suspected.
- Nonstructural components: Ceiling grid detached from adjacent CMU walls, dropped panels. Exterior veneer cracked at building corners; falling hazard remains. Interior glazing cracked in two places. No apparent damage to piping, ducts, or equipment within ceiling space.
- Contents: Spilled from shelves and cabinets, typical. Tall cabinets, unbraced, did not overturn.

For this example, all of the damage was recognized as earthquake damage. In general, the cause of the damage – earthquake, wind, fire, collision, etc. – is immaterial to the determination of whether SSD has occurred. However, as discussed below, the cause can affect the requirements that follow an SSD determination. Also, in some cases, pre-existing damage (for example, from prior events or deferred maintenance) can affect the SSD determination because SSD is based on capacity loss relative to the pre-event condition. Nonstructural

[9] The Risk Category of a building is assigned based on Section 1604.5 in the 2015 IBC. Risk Category II refers to buildings and other structures except those listed in Risk Categories I, III, and IV. Risk Category III refers to buildings and other structures that represent a substantial hazard to human life in the event of a failure. For schools (Group E), any structure housing more than 250 occupants would be in Risk Category III.

and contents damage does not count toward SSD but can be helpful in understanding the mechanism of the structural damage. Falling hazards, or the safety of the building in its damaged state, do not affect SSD. Finally, whether the structure was properly designed, and whether the damage was surprising or predictable, do not affect SSD.

Figure 1. Stepped cracking in masonry wall with buckling and out-of-plane spalling of CMU shell at toe of wall segment.
Photo: Jaclyn O'Laughlin.

Figure 2. Stepped cracking in masonry wall with up to 1 inch horizontal separation between units.
Photo: EERI Clearinghouse.

Figure 3. Damaged CMU removed, revealing undamaged steel tube column.
Photo: EERI Clearinghouse.

SSD Determination

<u>SSD to the gravity system:</u> With no apparent damage to the steel framing, and with the steel gravity system apparently unaffected in its ability to carry the existing dead and live loads, **it is concluded that SSD to the gravity system has not occurred**.

If the CMU partitions were essential to the gravity system, one would have to consider whether they had lost capacity relative to dead and live loads; in this example, however, the steel framing is understood to work independent of the CMU. This is why it is important to have an understanding of the structural system. An adequate understanding might require review of original plans or some destructive investigation.

Had the steel (or steel plus CMU) gravity system sustained SSD, that SSD would be treated as SSD to the lateral system because the damage was caused by earthquake (IEBC Sections 404.3.1 or 606.2.3.1).

A determination that the gravity system has not sustained SSD is not an indication that it was originally designed or constructed properly or that it would be adequate for current design loads.

<u>SSD to the lateral system:</u> With an understanding of the building's structural systems, it appears that the lightly reinforced CMU partitions provided most of the resistance to the lateral earthquake loads, even if they might not have been designed to do so. This can often be the case in older buildings, especially in regions of low

seismicity where earthquake design was not prioritized. In this example, then, the CMU partitions comprise the *de facto* lateral force-resisting system.

Narrow stepped cracks along CMU joints are typically the first signs that a wall has felt some in-plane loading. Normally, however, this light cracking does not indicate a substantial capacity loss. That is, if such a wall were to be loaded again by another earthquake, its ultimate strength and stability would be similar whether or not it started with light joint cracks. Thus, the stepped cracking observed throughout the building does not represent SSD.

The two other damage patterns – one-inch wide cracks and buckled or spalled units – do indicate a more fundamental change to the north-south walls' pre-earthquake condition. With the joints separated and the toe of certain wall segments starting to disintegrate, it can be reasonably judged that the damaged wall would perform in a degraded fashion under additional earthquake loading. Does this represent a 33 percent capacity loss to an entire story as the definition of SSD requires? This is a matter of judgment, and any conclusion is subject to review. For this example, it is judged that the change of state represented by the two advanced damage patterns does represent a substantial capacity loss, so **it is concluded that SSD to the lateral system has occurred** at each story in the north-south direction.

Where a damaged lateral system was apparently not designed or detailed to resist earthquake loads, as in this example, one might argue that SSD has not occurred because the CMU partitions offered no *reliable* lateral capacity even before the earthquake. If they had no capacity to lose, then there can be no loss, and the damage is cosmetic or nonstructural, not SSD. Within the logic of the IEBC, however, existing non-conforming conditions are often accepted, so every structure can be said to have at least a *de facto* lateral system with some capacity, even if it is weak and highly damageable.

Implications of SSD and Other Considerations

With lateral system SSD judged to exist, the structure is subject to the requirements of IEBC Sections 404.2 or 606.2.2. Generally this requires a structural evaluation and possibly a retrofit for both wind and seismic effects.

- The example building, assigned to Seismic Design Category B, would normally be exempt from the seismic work, but the exception does not apply because the damage was itself caused by an earthquake.
- For the wind evaluation, the loads are the same as those used for new construction (Sections 404.2.1 or 606.2.2.1). If the evaluation finds deficiencies, since the SSD was not caused by wind, the wind loads for retrofit may be those that applied at the time of the original 1975 construction (Sections 404.2.3 or 606.2.2.3). Thus, if the building was properly designed and constructed in 1975, it is likely that little, if any, wind retrofit will actually be required.
- For both the seismic evaluation and retrofit, reduced seismic loads are allowed (Sections 404.2.1 and 404.2.3 or 606.2.2.1 and 606.2.2.3). IEBC Chapter 3 allows the use of *ASCE 41* for evaluation and retrofit in lieu of IBC provisions for new construction. The *ASCE 41* performance objective, given in Table 301.1.4.2, will depend on whether this school building would be assigned to Risk Category II or III. In either case, because of apparent deficiencies in the pre-earthquake lateral system, it is likely that the building will require seismic retrofit in addition to repair.
- Substantial Damage need not be considered for this example because the building is not in a flood hazard area.
- If repair of the damage, not counting any triggered wind or seismic upgrade, would cost more than 50 percent of the building's replacement cost, FEMA policy allows replacement. The wind and seismic evaluation and retrofit would thus be avoided. The replacement building would be designed with IBC provisions for new construction. This was the case for this particular example.

EXAMPLE 2– HURRICANE DAMAGE

The following hypothetical example illustrates application of the IEBC's SSD provisions to wind damage.

Building Description

- Public middle school classroom building, with six classrooms in a line. If built new, the building would be assigned to Risk Category II or III, depending on the total occupant load.
- 1 story above grade, about 6000 gsf.
- Built in 1988.
- Gravity system: Wood roof trusses bearing on short-direction wood frame shear walls and on wood post and beam framing.
- Lateral system: Wood frame shear walls. The walls in the short direction (parallel to the roof trusses) carry little gravity load. The walls in the long direction also act as bearing walls supporting a portion of the roof trusses.
- Key nonstructural components: Metal roof panels. Suspended panelized ceilings with integrated light fixtures.
- Not in a flood hazard area.
- Moderate seismicity. If built new, the building would be assigned to Seismic Design Category C.

Most of the building attributes – its age, size, quality of design or construction – are immaterial to the determination of SSD. The most important information involves the gravity and lateral structural systems, as they affect one's understanding of the observed damage.

Damage Description

- Roof trusses: Trusses lifted and blown off over two classrooms at one end, about one third of the building footprint (Figure 4).
- Post and beam framing: Framing collapsed where the trusses blew off (Figure 4).
- Shear walls: Two short-direction shear walls collapsed at the end where the trusses blew off (Figure 4). Other short-direction walls and all long-direction walls were undamaged by wind, but there was damage due to rain through the damaged roof.
- Roof: Roof panels blown off over about four classrooms, or two thirds of the building footprint.
- Nonstructural components: Windowsand shades damaged by wind-borne debris. Extensive water damage to interior finishes.
- Contents: Extensive loss due to wind and water damage.

For this example, all of the damage was recognized as hurricane wind damage. In general, the cause of the damage – earthquake, wind, fire, collision, etc. – is immaterial to the determination of whether SSD has occurred. However, as discussed below, the cause can affect the requirements that follow an SSD determination. Also, in some cases, pre-existing damage (for example, from prior events or deferred maintenance) can affect the SSD determination because SSD is based on capacity loss relative to the pre-event condition. Nonstructural and contents damage does not count toward SSD but can be helpful in understanding the mechanism of the structural damage. Falling hazards, or the safety of the building in its damaged state, do not affect SSD. Finally, whether the structure was properly designed, and whether the damage was surprising or predictable, do not affect SSD.

Figure 4. Two classrooms at the far end of the six-classroom building completely destroyed. *Photo:FEMA*

SSD Determination

SSD to the gravity system: About one third of the building was completely destroyed once the trusses blew off. This exceeds the 30 percent area criterion and the 20 percent capacity loss criterion in the SSD definition. Therefore, **it is concluded that SSD to the gravity system has occurred**.

Because the SSD to the gravity system was caused by wind, it is treated as SSD to the lateral system (IEBC Sections 404.3.1 or 606.2.3.1).

SSD to the lateral system: In the long direction, the shear walls sustained little damage. In the short direction, two of seven shear walls were completely destroyed. This does not exceed the 33 percent criterion in the SSD definition. Conceptually, it is further observed that the two destroyed shear walls did not fail by overstress as shear walls. Rather, they were left exposed once the roof and framing failed. Therefore, **it is concluded that SSD to the lateral system did not occur**.

It might seem like an odd conclusion that under high wind loading, the building has more critical gravity system damage than lateral system damage. This is a result of the IEBC definitions, which do not have a parallel definition of SSD related to roof uplift failure, which is what drove the damage in this example. In the end, however, the provisions that give special attention to gravity systems damaged by wind or earthquake help lead the code to a reasonable conclusion.

Implications of SSD and Other Considerations

With gravity system SSD judged to exist but subject to treatment as lateral system SSD, the structure is subject to the requirements of IEBC Sections 404.2 or 606.2.2. Generally this requires a structural evaluation and possibly a retrofit for both wind and seismic effects.

- The example building, assigned to Seismic Design Category C, is exempt from seismic evaluation or retrofit because the SSD was not caused by an earthquake (Sections 404.2 or 606.2.2, Exception 1).
- With or without SSD, the extensive damage to this building almost certainly means that the repair, not counting any triggered wind or seismic upgrade, would cost more than 50 percent of the building's

replacement cost. In that case, FEMA policy would allow replacement, and the determination of SSD would be moot. The replacement building would be designed with IBC provisions for new construction.

- For the wind evaluation, the loads are the same as those used for new construction (Sections 404.2.1 or 606.2.2.1). Reduced wind loads are not allowed for the retrofit because the SSD was caused by wind (Sections 404.2.3 or 606.2.2.3).
- Substantial Damage need not be considered for this example because the building is not in a flood hazard area.