The IEBC's Roof Diaphragm Evaluation Requirements

When Reroofing Requires a Lateral Analysis

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Since its inception in 2003, the *International Existing Building Code* (IEBC) has contained a provision that triggers the evaluation and possible retrofit of roof diaphragms when certain buildings are reroofed. This provision has gradually evolved within the Work Area Method, unnoticed by some practitioners and readily avoided by others by reverting to the *International Building Code* (IBC) Chapter 34, Existing Buildings and Structures, or by using the Prescriptive or Performance Methods within the IEBC. However, Chapter 34 was eliminated from the 2015 IBC and the subject provision metastasized into the Prescriptive Method in the name of consistency. So today, engineers, architects, and owners are forced to contend with it (except in the narrow instances where the Performance Method is applicable) and, for those affected, the consequences can be unduly burdensome. This article recounts the origin and evolution of the provision since its introduction in 2003, discusses fundamental flaws in its requirements, and argues for the limitation of its applicability to either: 1) repairs that can be made to correct visible deterioration and/or deficiencies that are readily observed and remedied in the normal course of a roof replacement, or 2) specific geographic regions or building types known to have extraordinary roof diaphragm vulnerabilities.

Origin and Evolution

In the first edition of the IEBC (2003), a structural provision in Chapter 5, Alterations – Level 1, of the Work Area Method stated the following:

> **507.3 Roof Diaphragm**. Where roofing materials are removed from more than 50 percent of the roof diaphragm of a building or section of a building where the roof diaphragm is a part of the main wind force-resisting system, the integrity of the roof diaphragm shall be evaluated and if found deficient because of insufficient or deteriorated connections, such connections shall be provided or replaced.

To the authors' knowledge, nothing similar to this provision existed in any of the three model codes or other documents that served as the primary basis for the first edition of the IEBC. Furthermore, nowhere in the June 2001 Working Draft of the 2003 IEBC, prepared by the 2003 IEBC Drafting Committee, was there any mention of structural evaluations and/or upgrades to roof diaphragms associated with reroofing. As such, it was surprising that this provision appeared in the August 2001 Final Draft of the 2003 IEBC, also prepared by the 2003 IEBC Drafting Committee. It was subsequently learned from International Code Council (ICC) Technical Services that, based on recollections of certain ICC staff, the drafting committee reportedly had "concerns about the working draft and the lack of protection for high wind, and the focus was on the connections because they were often the cause of failures in high winds." Unfortunately, it appears that there are no meeting minutes or other written records

Figure 1. Wood diaphragm connections and shear walls not visible from the top surface of the diaphragm.

that provide elaboration or documentation regarding these alleged failures, including 1) locations, 2) wind speeds, 3) types of storms, e.g., thunderstorm, tornado, hurricane, chinook, 4) diaphragm materials, e.g., wood, steel, concrete, gypsum, etc., 5) connections of concern, or 6) the extent to which diaphragms were actually affected.

During their service lives, most buildings will be reroofed on multiple occasions, with the life of conventional roofing systems ranging from about 20 to 40 years. As elaborated in the IEBC *Commentary* since 2003, the provision intends to take advantage of this opportunity to observe and address potential problems that are otherwise obstructed from view. The provision applied only to diaphragm deficiencies from "insufficient and deteriorated connections," which apparently were the original drafting committee's focus. Any more extensive analytical evaluation would require an abundance of detailed information, including the locations and lengths of shear walls or frames and numerous connection details that are not necessarily observable from the top surface (*Figure 1*). As such, this provision appears to have been originally intended to identify and address obviously deficient or deteriorated connections based on a visual evaluation of a diaphragm's top surface only; deficiencies or deterioration beyond this could not be observed or easily remedied in the relatively short period available between removal and replacement of a roofing system. However, as outlined below, this intent has been lost in subsequent revisions to the IEBC.

Several modifications were made to the provision in the 2009 IEBC (606.3.2). One of these changes limited its applicability to "high-wind regions," defined as areas where the basic wind speed was greater than 90 mph (the baseline design speed for non-coastal areas of the U.S.) or areas that were within special wind regions as defined in Section 1609 of the IBC. A second change mandated that the diaphragm evaluation be performed using design wind loads required by the IBC for new buildings, and stated explicitly that wind uplift was to be included in the analysis. Where diaphragms and/or their connections in their current condition were unable to resist these loads, strengthening or replacement was required.

The 2012 IEBC (706.3.2) added clarification on the diaphragm connections that were to be addressed in the required evaluation, explicitly including connections of the roof diaphragm to roof framing and roof-to-wall connections. This edition also reduced the design wind load criteria to 75 percent of that required for new buildings.

Changes in the 2015 IEBC (707.3.2) consisted of updating the design wind speed consistent with the transition to ultimate loads in ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures*, i.e., 90 mph became 115 mph and adding a virtually identical provision to the Prescriptive Method (403.8). Also in 2015, Chapter 34, Existing Buildings and Structures, was removed from the IBC, leaving regulation of existing buildings solely up to the IEBC.

These requirements were unchanged in both the Work Area Method (706.3.2) and the Prescriptive Method (503.12) of the 2018 IEBC. The current provision in 706.3.2 reads as follows:

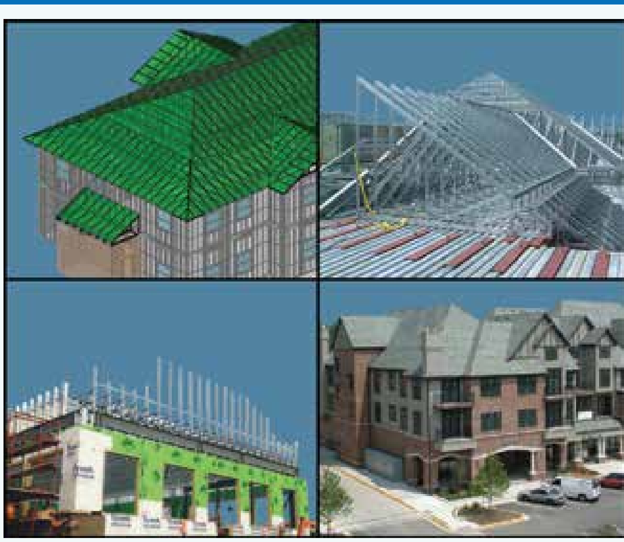
> **706.3.2 Roof diaphragms resisting wind loads in high-wind regions**. Where roofing materials are removed from more than 50 percent of the roof diaphragm or section of a building located where the ultimate design wind speed, V_{ult}, determined in accordance with Figure 1609.3(1) of the *International Building Code*, is greater than 115 mph (51 m/s) or in a special wind region, as defined in Section 1609 of the *International Building Code*, roof diaphragms, connections of the roof diaphragm to roof framing members, and roof-to-wall connections shall be evaluated for the wind loads specified in the *International Building Code*, including wind uplift. If the diaphragms and connections in their current condition are not capable of resisting 75 percent of those wind loads, they shall be replaced or strengthened in accordance with the loads specified in the *International Building Code*.

See *Figure 2* (*page 16*) for the reproduction of 2018 IBC Figure 1609.3(1) with areas conforming to the IEBC definition of "high-wind regions" highlighted.

Ramifications

A diaphragm evaluation strictly conforming to the current provision and its stated intent would ostensibly involve the following: 1) removal of all existing roofing down to the structural diaphragm for observation and, except where drawings are available and sufficiently detailed, collection of data to support the structural analysis; 2) engineering calculations, which cannot be performed extemporaneously in the field, evaluating the diaphragm and connection strengths to resist the prescribed design wind forces; 3) installation of temporary protection for the roof in anticipation of the possibility of resulting structural retrofit work; 4) both demobilization and subsequent remobilization of the roofing crew; 5) design and permitting of any necessary structural retrofits, 6) potentially hiring a subcontractor capable of installing the necessary structural retrofits, and 7) resuming installation of the replacement roofing system.

The authors suspect that such a sequence of events has rarely, if ever, occurred. More likely, the provision has been avoided by referencing an alternate chapter in the adopted code(s), the design professional, contractor, and/or building official never knew that the provision applied, or it was ignored. However, for conscientious design professionals working under the authority of attentive building officials, the only rational option has become to consult the construction drawings for the critical details well in advance of the work. In the absence of comprehensive construction documents, which is frequently the case,



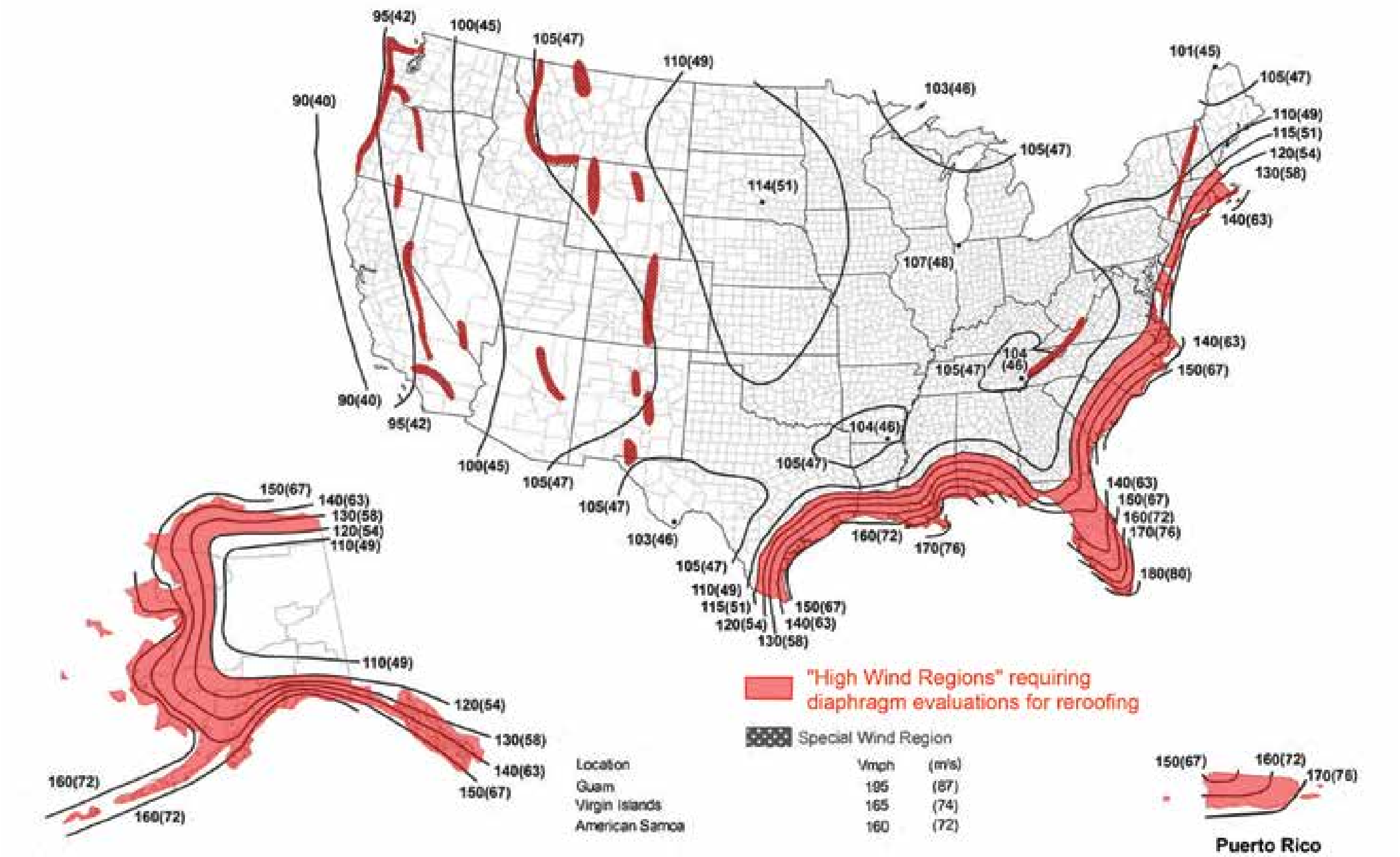


Figure 2. Reproduction of Figure 1609.3(1) annotated from the 2019 International Building Code; Copyright 2017.

the evaluators are compelled to document the structure themselves, making pre-construction destructive openings in the roofing, inspecting below-deck conditions from the interior, and then analyzing and designing any necessary structural retrofits to be bid and permitted in conjunction with the roofing contract. This work can result in significant increases in costs for the routine exercise of reroofing.

Flawed Foundation

Wind can and does cause structural damage to buildings due to shortcomings in the original codes, problems with the design, construction defects, accumulated deterioration, or some combination of these factors. However, while model codes, as well as design and construction practices, have generally improved over time, the safety and sufficiency of existing structures are only rarely revisited unless significant damage has occurred or if a proposed structural alteration or occupancy change triggers compliance with the provisions for new structures. One such instance is presented next to the subject diaphragm reroofing passages in the IEBC: the requirement that unreinforced masonry (URM) bearing wall parapets be braced when reroofing buildings in high seismic regions. This provision addresses an exceptional hazard demonstrated by repeated poor performance (in many cases, even in events much less severe than design), arguably justifying the imposition of costs on a building owner to abate a significant latent danger to the public.

To justify the high costs of retroactive diaphragm evaluations and upgrades, the authors believe there should be a commensurate extraordinary risk from wind-related diaphragm vulnerabilities. Such vulnerabilities may be regional, such as the URM parapet provision that only applies in Seismic Design Categories D through F. Likewise, diaphragm wind upgrades should be limited to regions or building types where extraordinary vulnerabilities have been observed. Coastal hurricane regions may be in this category, but the authors are not aware of any rigorous study that substantiates the existence or extent of any such extraordinary hazard associated with roof diaphragm performance. However, anecdotal evidence does suggest that buildings do collapse with some frequency in hurricane winds after roof diaphragm integrity is lost.

The authors reside and practice structural engineering along Colorado's Front Range in a special wind region where basic wind speeds range from 115 to 225 mph. Based upon their knowledge and experience investigating structural failures in this extraordinary wind climate, they are unaware of any remarkable incidence of diaphragm failures from high winds. Similarly, the results of an informal survey conducted among professional members of the Structural Engineers Association of Colorado in 2017 indicated no prevailing evidence of diaphragm vulnerabilities in Colorado's special wind region.

2021 IEBC and Beyond

ICC has approved modifications to the 2018 diaphragm provisions for inclusion in the 2021 IEBC. The revised provision in 706.3.2 will read as follows:

706.3.2 Roof diaphragms resisting wind loads in high-wind regions. Where roofing materials are removed from more than 50 percent of the roof diaphragm or section of a building located where the ultimate design wind speed, V_{ult}, determined in accordance with Figure 1609.3(1) of the *International Building Code*, is greater than 130 mph (58 m/s), roof diaphragms, connections of the roof diaphragm to roof framing members, and roof-to-wall connections shall be evaluated for the wind loads specified in the *International Building Code*, including wind uplift. If the diaphragms and connections in their current condition are not capable of resisting 75 percent of those wind loads, they shall be replaced or strengthened in accordance with the loads specified in the *International Building Code*.

Exception: Buildings that have been designed to comply with the wind load provisions in ASCE 7-88 or later editions.

The changes include: 1) an increase in the threshold wind speed from 115 to 130 mph (the wind speed above which glazed openings must be protected from impact in hurricane-prone regions), 2) elimination of any reference to special wind regions, and 3) an exception to the provision when the building under consideration has been designed to comply with what are judged to be comprehensive modern wind load requirements.

The authors worked to develop and promote the acceptance of these changes; however, in our opinion, they do not go far enough. If all the proposed changes had been adopted, diaphragm evaluations in the 2021 IEBC would be triggered only for buildings located in hurricane-prone regions where the ultimate design wind speed exceeds 130 mph. The authors believe this is important because, to their knowledge, there is no historical evidence substantiating the existence of any extraordinary diaphragm vulnerabilities to wind outside of hurricane-prone areas. Coastal wind regions differ significantly from those farther inland in the relationship between frequency and severity of high winds. Design for coastal regions is driven predominantly by extreme random events in an otherwise unexceptional wind climate. Compare this to downslope chinook winds along the Colorado Front Range driven by the weather phenomenon of air rising and falling over the Rocky Mountains, in which foothills communities experience high winds on a regular basis. Such winds are neither unusual nor unexpected, and local design and construction practices have necessarily evolved to keep buildings upright with their roofs intact. The relatively high inland frequency of such winds leaves a substantially smaller margin for deficiencies to remain undetected, as may have happened historically on the coasts.

The requirement that a building undergoes a diaphragm evaluation, involving a significant investigative and analytical effort by an engineer with the possibility of costly structural upgrades, is an extraordinary burden that should only be justifiable based on a commensurately extraordinary hazard. Otherwise, it is logical, appropriate, and consistent with longstanding engineering practice to let grandfathered structures stand unaffected by the increasingly complex regulations governing new structures. It is unreasonable to attempt to keep the entire building stock up to date with model codes as they continue to evolve. Retroactive upgrades are an appropriate tool when the costs of inaction definitively outweigh the costs of action. But that burden should be limited to where there is sufficient evidence of major structural concern. Tying the trigger to only hurricane-prone regions would limit the provision's scope to suspected areas of vulnerability that are threatened by extraordinary winds.▪

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