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Calculating Anchorage Capacities for Nonstructural Components Used on 2012 IBC Projects

It has come to VISCMA's attention that there are many well-meaning engineers involved in the design and attachment of mechanical equipment and other non-structural components to concrete who are creating designs that are not compliant with the 2012 version of the IBC. This is not surprising in that the regulations guiding these requirements are tedious and convoluted. For the less the scrupulous, this also allows the potential supplier to provide a substandard system at a low cost without being questioned about it.

This is of particular concern to the member companies of VISCMA as it has been and continues to be our goal to provide safe code compliant designs to the market to ensure occupant safety and to limit damage to the components and contents should a seismic event occur.

This document has been drafted as an aid to engineers who are not members of VISCMA, but who may be involved in the attachment and restraint of non-structural components. It will offer a guide through the code documents detailing the 2012 IBC requirement to increase the design loads by a factor of 2.5 (or reduce anchor capacities to 40% of their rating) before selecting concrete anchorage components.

This new code requirement has to do with the unpredictable failure mode of anchors in concrete. If the failure mode is a ductile failure of the steel portion of the anchor or of some intermediate bracket between the anchor and the component being restrained, there is no need to include this added factor. If however, the failure mode is in the brittle concrete itself, particularly in dynamically loaded situations, the ability to predict the capacity is greatly reduced. This added factor is intended to address this unpredictability.

This is of particular concern to those working with non-structural components as the attachment of virtually every non-structural component involves a brittle failure in the concrete. There are several reasons for this:

1) Anchor manufacturers' design their products for various grades of concrete and to optimize the capacity for higher strength concrete members, the steel is well over-designed for the concrete typically found in construction applications.
2) From a liability standpoint, Anchor manufacturers also do not want the anchor to be the weakest link. (If there is a failure, they want to ensure that it is not their fault.)

3) Restraint components or bracketry tend not to be the weak link as that are designed to achieve high capacities if through bolted to the structure. Thus they cannot be counted on to be a "fuse" for the anchors.
4) Equipment manufacturer's also do not want to be the weak link in the chain and they typically design and test their components to resist significantly higher seismic or wind conditions than might be applicable for any particular project.

As a result, it is a safe bet that 9 times out of 10, the concrete attachment failure will be brittle.

At the back of this document, you will find copies of all of the latest code documents and the "official" verbiage for reference. Looking at these reference documents, here is a summary of the code language:

The first excerpt, identified as Reference (1) is the original verbiage from sections D.3.3.4, 5 and 6, the non-structural component applicable portions of ACI 318-08 Appendix D. This is the initial code reference citing the ductile/brittle issue and the requirement to reduce the anchor capacity to 40% of its computed value when dealing with a brittle failure. While included here, the basic verbiage is relatively meaningless as the entire segment is superseded by exceptions taken in the 2012 IBC document.

The second excerpt, identified as Reference (2) is from ASCE 7-05 (13.4.2). This was the basis for the anchorage design used on 2006 and 2009 IBC projects. It indicates that designs need to develop a capacity 1.3 times the prescribed force based on an analysis (assuming the anchor is the limiting element and it always is). It also indicates (thanks to the errata dated 9/15/06 which adds a bunch of "or"s to the segment) that anchors prequalified to ACI 355.2 are OK with no further qualifications or de-ration. Previous to these errata, the line items were linked by "and"s which eliminated this option. This change effectively allowed the adoption of this anchor de-ration factor to be delayed one IBC Code cycle. Note however that this older standard is <u>not</u> linked to the 2012 IBC.

The third excerpt, identified as Reference (3) is from ASCE 7-10 (13.4.2). This is the basis for the anchorage of non-structural components in the 2012 IBC. It basically says three things.

1) Anchors are to be designed per ACI 318 D (which requires de-rating the anchors to 40% of their rating, see previous reference).
2) Anchors in masonry must either be designed based on the strength of a ductile steel element or the loads must be increased by a factor of 2.5 (basically the same as the reduction to 40% of the allowable on the anchor rating).
3) Post installed anchors must be pre-qualified per ACI 355.2 in addition to the other requirements.

Reference (4) is drawn from the 2012 IBC. It is made up of entirely errata generated segments which I have patched together. For our purposes, it will be treated as a single entity rather than as a number of smaller segments.

First off, in section 1905.1.9, it clearly links the ACI 318 reference to ACI 318-08. It then replaces the verbiage in section D3.3.4 with completely new verbiage which now says that the anchor strength must be governed by the steel strength of a ductile steel element as the mode of failure unless either D.3.3.6 or D.3.3.7 is satisfied.

D.3.3.6 indicates that the strength of the anchorage can be reduced to 40% of its design strength. D.3.3.7 is relevant to light frame construction and has nothing to do with items like equipment. Thus this path leads us to the 60% capacity reduction.

There are, however additional options listed in D3.3.4.

1) Exception 1 has to do with building structures and is not applicable to non-structural components.
2) Exception 2 has to do with the attachment of wooden sill plates and is also not applicable to non-structural components.
3) Exception 3 has to do with the attachment of cold formed sheet metal framing channels to the structure and again is not applicable to non-structural components.
4) Lastly, Exception 4 takes us back to sill plates and foundation tracks which also are not non-structural components.

Therefore, any option that we chose in section D3.3.4 leads us to the requirement of either a ductile element or the need to reduce the anchor capacity to 40% of its initial value.

The only relevant comment left in the 2012 IBC errata is the reference back to ACI section D3.3.5 where, as luck would have it, another option to section D3.3.4 is identified. The option however is relatively meaningless however as it indicates only that in lieu of having the ductile element built into the anchor itself, it is possible to replace it with an attachment bracket or component that will yield in a ductile manner below the brittle failure load of the concrete connection.

Back checking the code references to ensure that the proper ones are cited. The following two items Reference (5) and (6) complete this review.

Reference 5 is out of the original release of the 2012 IBC. Relative to section 1905.1.10 (underlined), ASCE 7-10 is clearly the appropriate ASCE version to reference.

Likewise, in Reference 6, the most recent Errata change to the reference section of the 2012 IBC, The reference to ACI-318-11 has clearly and purposely been changed to ACI-318-08.

Therefore, when working with concrete anchors used to attach non-structural components in the 2012 IBC, the code clearly states that either the designer must ensure one of the three conditions listed below are met:

1) The steel portion of the anchor is the weak link,
2) That a ductile metal bracket with less capacity than that generated by the concrete anchorage is fitted, or
3) That the permitted capacity of the anchor is reduced to 40% of its rating when the anchor selection is made.

In October 2013, ASCE 7-10 released Supplement No 1. While this has no direct legal bearing on the 2012 IBC code, it does have a direct bearing on the California Building Code and is indicative of where the IBC is heading. It has also been accepted by ICC (the code writing authority) as the preferred method of analysis even if it is not directly linked to the 2012 IBC. This Supplement introduces a new factor called Ω_0. This factor is to be used in lieu of the 40% deration factor indicated in this document for the anchors and is a load increasing factor that is applied to the horizontal seismic force generated by a seismic event. The value is not a constant and it does vary between 1.5 and 2.5 depending on the equipment and installation type.

This type of analysis is felt to be an improvement over using an unchanging force on the load side of the equation and applying the original factor that decreases the anchor load capacity in that it better fulfills the intent of the code. This is because there is not a linear relationship between the increase in forces at a restraint point and an increase in the primary driving forces. Since the actual unknown is the driving forces and not the anchor capacity it makes sense to have the factor affect the unknown rather than the known. In some cases, the difference in forces and anchorage safety factors can be substantial.

The downside to this is that there are basically two levels of analysis required. The first is to exclude the factor and evaluate those components that are not impacted by the anchor failure mode. The second is to re-run the analysis at the higher force levels to properly analyze the anchorage. This frequently requires that an assumption needs to be made up front as to the mode of failure of the anchor. The analysis is then run and if the assumption was in error, than the entire analysis needs to be rerun with a new set of assumptions. This essentially doubles the amount of work it takes to perform a proper analysis.

The newest IBC(2015) will most certainly adopt this methodology.

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Excerpts from the most current code documents

Reference (1) - ACI 318-08 Appendix D (original language for reference only, this has been completely superseded by comments in ASCE 7 and the IBC)

D.3.3.4 — Anchors shall be designed to be governed by the steel strength of a ductile steel element as determined in accordance with D.5.1 and D.6.1, unless either D.3.3.5 or D.3.3.6 is satisfied.

D.3.3.5 — Instead of D.3.3.4, the attachment that the anchor is connecting to the structure shall be designed so that the attachment will undergo ductile yielding at a force level corresponding to anchor forces no greater than the design strength of anchors specified in D.3.3.3.

D.3.3.6 — As an alternative to D.3.3.4 and D.3.3.5, it shall be permitted to take the design strength of the anchors as 0.4 times the design strength determined in accordance with D.3.3.3. For the anchors of stud bearing walls, it shall be permitted to take the design strength of the anchors as 0.5 times the design strength determined in accordance with D.3.3.3.

Reference (2) - ASCE 7-05 as updated by Errata Dated 9/15/06 (used on IBC 2006 and IBC 2009)

13.4.2 Anchors in Concrete or Masonry. Anchors embedded in concrete or masonry shall be proportioned to carry the least of the following:

a. 1.3 times the force in the component and its supports due to the prescribed forces.
b. The maximum force that can be transferred to the anchor by the component and its supports.

The value of R_p used in Section 13.3.1 to determine the forces in the connected part shall not exceed 1.5 unless

a. The component anchorage is designed to be governed by the strength of a ductile steel element or
b. The design of post-installed anchors in concrete used for the component anchorage is prequalified for seismic applications in accordance with ACI 355.2 or
c. The anchor is designed in accordance with Section 14.2.2.17.

Reference (3) - ASCE 7-10 (Basis for IBC 2012)

13.4.2 Anchors in Concrete or Masonry.

13.4.2.1 Anchors in Concrete

Anchors in concrete shall be designed in accordance with Appendix D of ACI 318.

13.4.2.2 Anchors in Masonry

Anchors in masonry shall be designed in accordance with TMS 402/ACI 530/ASCE 5. Anchors shall be designed to be governed by the tensile or shear strength of a ductile steel element.

EXCEPTION: Anchors shall be permitted to be designed so that the support that the anchor is connecting to the structure undergoes ductile yielding at a load level corresponding to anchor forces not greater than their design strength, or the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the component.

13.4.2.3 Post-Installed Anchors in Concrete and Masonry

Post-installed anchors in concrete shall be prequalified for seismic applications in accordance with ACI 355.2 or other approved qualification procedures. Post-installed anchors in masonry shall be prequalified for seismic applications in accordance with approved qualification procedures.

Reference (4) - Modifications to the ACI 318-08 Appendix D language put forth in the 2012 IBC (Compiled from the most current Errata as indicated below.)

From 7-9-12 Errata (Reference (4) cont)

1905.1.9 ACI 318-08, Section D.3.3. ~~Delete~~ Modify ACI 318-08 Sections D3.3.4 through D.3.3.6 and add Section ~~through~~ D3.3.7 ~~and replace with the following~~ to read as follows:

~~*D.3.3.4 – The anchor design strength associated with concrete failure modes shall be taken as 0.75ØN_n and 0.75ØV_n, where Ø is given in D4.3 or D4.4, and N_n and V_n are determined in accordance with D5.2, D5.3, D5.4, D6.2 and D6.3, assuming the concrete is cracked unless it can be demonstrated that the concrete remains uncracked.*~~

From 2-27-13 Errata (Reference (4) cont)

~~*D.3.3.5*~~ D3.3.4–

Anchors shall be designed to be governed by the steel strength of a ductile steel element as determined in accordance with D.5.1 and D.6.1, unless either D.3.3.6 or D.3.3.7 is satisfied.

From 7-19-12 Errata (Reference (4) cont)

Exceptions:

1. Anchors designed to resist wall out-of-plane forces with design strengths equal to or greater than the force determined in accordance with ASCE 7 Equation 12.11-1 or 12.14-10 need not satisfy Section ~~D.3.3.5~~ D.3.3.4.

2. ~~D.3.3.5~~ D.3.3.4 need not apply and the design shear strength in accordance with D.6.2.1(c) need not be computed for anchor bolts attaching wood sill plates of bearing or non-bearing walls of light-frame wood structures to foundations or foundation stem walls provided all of the following are satisfied:

2.1. The allowable in-plane shear strength of the anchor is determined in accordance with AF&PA NDS Table 11E for lateral design values parallel to grain.

2.2 The maximum anchor nominal diameter is 5/8 inches (16 mm).

2.3. Anchor bolts are embedded into concrete a minimum of 7 inches (178 mm).

2.4. Anchor bolts are located a minimum of 1-3/4 inches (45 mm) from the edge of the concrete parallel to the length of the wood sill plate.

2.5. Anchor bolts are located a minimum of 15 anchor diameters from the edge of the concrete perpendicular to the length of the wood sill plate.

2.6. The sill plate is 2-inch or 3-inch nominal thickness.

3. Section ~~D.3.3.5~~ D.3.3.4

From 2-27-13 Errata (Reference (4) cont)

need not apply and the design shear strength in accordance with Section D.6.2.1(c) need not be computed for anchor bolts attaching cold-formed steel track of bearing or non-bearing walls of light-frame construction to foundations or foundation stem walls provided all of the following are satisfied:

3.1. The maximum anchor nominal diameter is 5/8 inches (16 mm).

3.2. Anchors are embedded into concrete a minimum of 7 inches (178 mm).

3.3. Anchors are located a minimum of 13/4 inches (45 mm) from the edge of the concrete parallel to the length of the track.

3.4. Anchors are located a minimum of 15 anchor diameters from the edge of the concrete perpendicular to the length of the track.

3.5. The track is 33 to 68 mil designation thickness.

Allowable in-plane shear strength of exempt anchors, parallel to the edge of concrete shall be permitted to be determined in accordance with AISI S100 Section E3.3.1. *(this section needs to be even with Exception 3)*

From 7-19-12 Errata (Reference (4) cont)

4. In light-frame construction, design of anchors in concrete shall be permitted to satisfy D.~~3.3.8~~ 3.3.7.

From 7-19-12 Errata (Reference (4) cont)

~~D.3.3.6~~ D3.3.5– Instead of ~~D.3.3.5~~ D3.3.4, the attachment that the anchor is connecting to the structure shall be designed so that the attachment will undergo ductile yielding at a force level corresponding to anchor forces no greater than the design strength of anchors specified in ~~D.3.3.4~~ D.3.3.3.

Exceptions:

1. Anchors in concrete designed to support nonstructural components in accordance with ASCE 7 Section 13.4.2 need not satisfy Section ~~D.3.3.6~~ D.3.3.5.

2. Anchors designed to resist wall out-of-plane forces with design strengths equal to or greater than the force determined in accordance with ASCE 7 Equation 12.11-1 or 12.14-10 need not satisfy Section ~~D.3.3.6~~ D.3.3.5.

~~D.3.3.7~~ D.3.3.6 - As an alternative to ~~D.3.3.5~~ D.3.3.4 and ~~D.3.3.6~~ D.3.3.5, it shall be permitted to take the design strength of the anchors as 0.4 times the design strength determined in accordance with ~~D.3.3.4~~ D.3.3.3.

~~D.3.3.8~~ D.3.3.7 – In light-frame construction, bearing or non-bearing walls, shear strength of concrete anchors less than or equal to 1 inch [25 mm] in diameter of sill plate or track to foundation or foundation stem wall need not satisfy ~~D.3.3.7~~ D.3.3.6 when the design strength of the anchors is determined in accordance with D.6.2.1(c).

Reference (5) - Original Referenced Standards in the 2012 IBC

ASCE/SEI American Society of Civil Engineers
Structural Engineering Institute
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Standard reference number	Title	Referenced in code section number
5—11	Building Code Requirements for Masonry Structures	1405.6, 1405.6.1, 1405.6.2, 1405.10, 1604.3.4, 1705.4, 1705.4.1, 1807.1.6.3, 1807.1.6.3.2, 1808.9, 2101.2.2, 2101.2.3, 2101.2.4, 2101.2.5, 2101.2.6, 2103.9, 2103.12, 2103.13, 2103.14, 2104.1, 2104.1.1, 2104.1.2, 2104.1.3, 2104.2, 2104.3, 2104.4, 2105.2.2.1, 2105.2.2.1.2, 2105.2.2.1.3, 2106.1, 2107.1, 2107.2, 2107.3, 2107.4, 2108.1, 2108.2, 2108.3, 2109.1, 2109.1.1, 2109.2, 2109.2.1, 2109.3, 2110.1
6—11	Specification for Masonry Structures	1405.6.1, 1705.4, 1807.1.6.3, 2103.9, 2103.12, 2103.13, 2103.14, 2104.1, 2104.1.1, 2104.1.2, 2104.1.3, 2104.2, 2104.3, 2104.4, 2105.2.2.1.1, 2105.2.2.1.2, 2105.2.2.1.3
7—10	Minimum Design Loads for Buildings and Other Structures	202, Table 1504.8, 1602.1, 1604.3, Table 1604.5, 1604.8.2, 1604.10, 1605.1, 1605.2.1, 1605.3.1, 1605.3.1.2, 1605.3.2, 1605.3.2.1, 1607.8.1, 1607.8.1.1, 1607.8.1.2, 1607.8.3, 1607.12.1, 1608.1, 1608.2, 1608.3, 1609.1.1, 1609.1.2, 1609.3, 1609.5.1, 1609.5.3, 1609.6, 1609.6.1, 1609.6.1.1, 1609.6.2, Table 1609.6.2, 1609.6.3, 1609.6.4.1, 1609.6.4.2, 1609.6.4.4.1, 1611.2, 1612.4, 1613.1, 1613.3.2, Table 1613.3.3(1), Table 1613.3.3(2), 1613.3.5, 1613.3.5.1, 1613.3.5.2, 1613.4, 1613.4.1, 1614.1, 1705.11, 1705.12, 1705.12.3, 1705.12.4, 1803.5.12, 1808.3.1, 1810.3.6.1, 1810.3.9.4, 1810.3.11.2, 1810.3.12, 1905.1.1, 1905.1.2, 1905.1.9, 2205.2.1, 2205.2.2, 2206.2, 2209.1, 2210.2, 2304.6.1, 2404.1, 2505.1, 2505.2, 2506.2.1, 3404.4, 3404.5
8—02	Standard Specification for the Design of Cold-formed Stainless Steel Structural Members	1604.3.3, 2210.1, 2210.2
19—09	Structural Applications of Steel Cables for Buildings	2208.1, 2208.2
24—05	Flood Resistant Design and Construction	1203.3.2, 1612.4, 1612.5, 3001.2, G103.1, G401.3, G401.4
29—05	Standard Calculation Methods for Structural Fire Protection	722.1
32—01	Design and Construction of Frost Protected Shallow Foundations	1809.5

Reference (6) - Modifications to the Referenced Standards in the 2012 IBC inn Errata dated 7-19-12

CHAPTER 35
REFERENCED STANDARDS

ACI

ACI 318-11	Building Code Requirements for Structural Concrete	1905.1.8, ~~1905.1.9,~~ 1905.1.10
ACI 318-08	Building Code Requirements for Structural Concrete	1905.1.9

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In partnership with FEMA and ASCE, VISCMA also publishes three Seismic Installation and Inspection Manuals designed to assist field personnel.

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