Defect, damage, and who should pay

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Abstract: Through the continued development and implementation of building information modeling (BIM) and other technological innovations in structural design of buildings, problems that may once have plagued a traditional building design are now discovered and addressed before they reach the fabrication and/or construction stage. However, even the best design and high-quality detailing cannot prevent construction defects if the implementation is not consistent with the design requirements. This paper aims at a holistic presentation of construction defects from their root-cause inception to the damage that they can cause, to the question as to who is responsible for the resultant financial consequences. The paper also provides context to the insurance coverage side of construction defects to assess how a defect/damage claim may be structured around specific "perils, occurrences, and/or exclusions." Several real-world examples are presented to illustrate how robust, straight-forward designs can still not be good enough if the construction team can make repeated mistakes that harm the performance of the building. The paper concludes with a window into the future of project development, design, and construction.

1. Background

1.1. Introduction

Through the continued development and implementation of building information modeling (BIM) and other technological innovations in structural design of buildings, problems that may once have plagued a traditional building design are now discovered and addressed before they reach the fabrication and/or construction stage. However, even the best design and high-quality detailing cannot prevent construction defects if the implementation is not consistent with the design requirements. This paper discusses defects and their resulting damage that occur in construction projects of all sizes all over the world.

1.2. Definitions

The following definitions provide a framework for the topics that will be explored in this paper. The legal/insurance definitions are sourced from Black's Law Dictionary (Black's), whereas the engineering terms have alternate sources or are directly defined by the authors.

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1.2.1. Legal/Insurance:

- Consequence – The result following in natural sequence from an event which is adapted to produce, or to aid in producing, such result; the correlative of "cause" (Black’s, P. 378).
- Damage – Loss, injury, or deterioration, caused by the negligence, design, or accident of one person to another, in respect of the latter’s person or property (Black’s, P. 466).
- Defect – The want or absence of something necessary for completeness or perfection; a lack or absence of something essential to completeness; a deficiency in some thing essential to the proper use for the purpose for which a thing is to be used (Black’s, P. 560).
- Occurrence – A coming or happening; any incident or event, especially one that happens without being designed or expected (Black’s, P. 1231).
- Peril – The risk, hazard, or contingency insured against by a policy of insurance (Black’s, P. 1296).

1.2.2. Engineering:

- Failure – The inability of a structure or system to perform its intended function.
- Margin of Safety (Code) – The difference between the calculated resistance provided by a structure or system and the code-level demand on that same structure or system.
- Maximum Considered Event – The largest event (e.g., wind, seismic) that the governing design standards consider.
- Structural Reliability – The calculation and prediction of the probability of a limit state violation for a structure or system (Melchers, P. 1).
- Resistance – The calculated capacity a structure or system to withstand loading.
- Toughness – A measurement of the ability of a material, component, or system to deform and absorb load without fracture.

2. Defective Construction and Resulting Damage

2.1. Defective Construction

Defective construction or construction with an “absence of something necessary for completeness” plague all projects, big and small. It is when these defects affect the performance of a structure and/or result in damage thereto that they can become problematic. In general, construction defects describe a sub-category of defective construction where the builder/contractor does not perform the construction in compliance with the engineer/architectural plans and specifications. This, however, is just one subset of defects that can affect a structure. Other types of defects include 1) design defects – where a critical component may be omitted from or changed within the architectural or engineering drawings, or 2) performance defects – where necessary performance objective for the project are not communicated between the owner, design team, and/or contractors.

2.1.1. Construction Defects

As presented prior, a construction defect arises when the contractor(s) or sub-contractor(s) fail to build the structure in conformance with approved plans and specifications. Generally, the plans and specifications are put together by registered design professionals to meet at least the minimum standard requirements adopted by the local official having jurisdiction though a “building code”. As such, the building code requirements do not preclude designers from providing more robust structures if they owner so desires.

Defects during the construction phase can occur for several reasons, including:

– Unknowledgeable/unskilled construction team;
– Cost cutting measures, often called cost-engineering or value-engineering;
– Schedule pressure; and
– Incorrect tools and equipment.

While all of these possible reasons can lead to a single, often innocuous construction defect, such a “mistake” when repeated throughout the structure can lead to major serviceability or at worse, safety problems. Thus, even if the drawings and specifications are perfect, a repeated erroneous implementation can render the project a failure.

There is a plethora of examples of construction defects and their “educational value” cannot be overestimated, thus their discussions through fora like the international conference “Awarie Budowlane” provide a most important role in the dissemination of lessons learned. One example case is the construction of the new span of the San Francisco-Oakland Bay Bridge presented by Moncarz and Bishop (2015) in which the following main construction defects are discussed:

– Several high-strength, galvanized anchor rods and bolts have broken, potentially due to hydrogen-induced corrosion (Figure 1);
– Steel guardrail attachments to the bridge deck have allowed water leakage, permitting corrosion of the deck;
– Numerous weld inspections have indicated substandard weld quality and potential weld cracking; and;
– The misalignment of deck sections led to in-situ retrofits potentially impacting the performance during a seismic event.

Figure 1. Evidence of corrosion around bolts in the San Francisco-Oakland Bay Bridge (photograph courtesy of SF Chronicle).

Another example, this time of a repeated construction defect, is the substitution of incorrectly sized powder actuated fasteners in lieu of the appropriately specified fasteners. In this case, the contractor repeatedly used too short fasteners (Figure 2), which rendered the anticipated margin of safety for the structural connection of the floor diaphragm to the lateral load-resisting system insufficient. For this investigation, many random exploratory openings were conducted to ascertain the extent of incorrect fastener sizing. Statistical extrapolation was then implemented to determine the expected number of times the fasteners throughout the building were of the incorrect size. In this instance, the use of a few short fasteners probably would not have made a significant impact, but when incorrect fasteners were found to be almost universally used, the impact on the structural performance was quite significant.

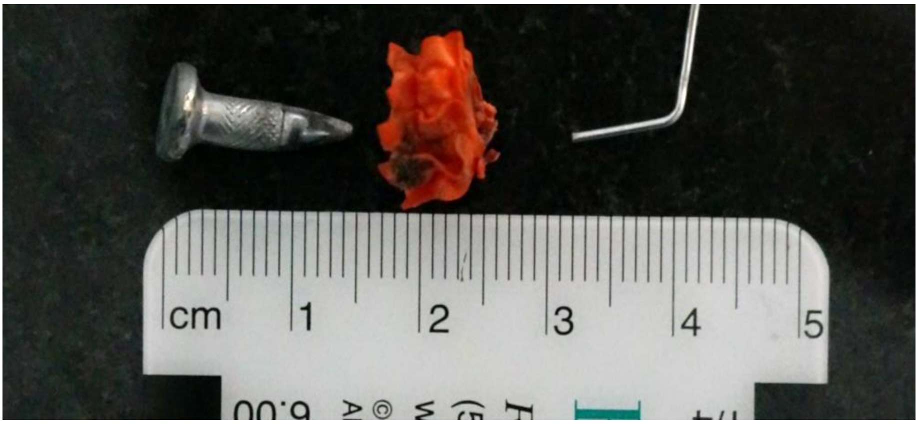

Figure 2. Universally incorrectly-sized fasteners installed at a project.

2.1.2. Design Defects

Design defects occur when the designer (e.g., architect, structural engineer, mechanical engineer) errs, resulting in a design which does not meet the functional and/or structural requirements of the constructed facility. For example, if a structural engineer relies on incorrect seismic characteristics for the site, the structural lateral system of the building might be incapable of meeting the probable seismic demand to a risk level explicitly or intrinsically defined by the governing standards.

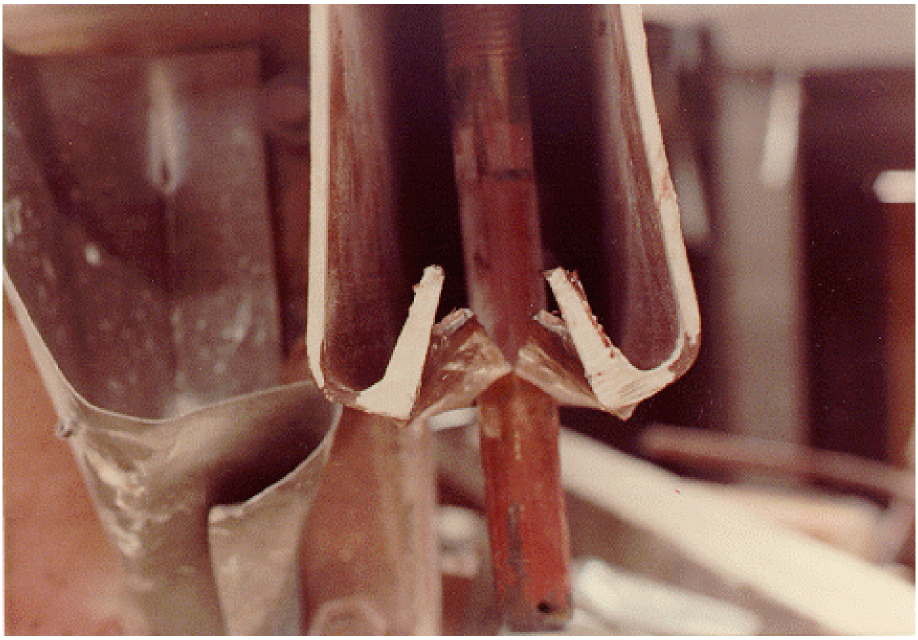

Figure 3. Failed support rail connection at the Hyatt Regency Hotel. Photograph from Dr. Lee Lowery, Jr., P.E.

A well-known example of a design defect is the collapse of the atrium walkways in the Hyatt Regency Hotel in Kansas City, Missouri, United States in July of 1980. It was determined after the collapse (see, e.g., Moncarz and Taylor (2000) and Marshall (1982)) that the failure was a result of a change in connection details, which were approved by the engineer of record. The adjustment resulted in a two-fold increase in the connection loads, which ultimately led to the system collapse (Figure 3).

2.1.3. Performance Defects

While at first not as egregious as construction or design defects, at the societal level performance defects are consuming much greater financial resources than the first two. The decades of construction without attention to energy efficiency of commercial, institutional, and residential buildings resulted in growing demand for energy, that in turn resulted in massive scale development of new generating plants without any regard for their environmental impact. Leaking roofs, moisture ingress and subsequently organic growth on interior finishes, acoustic insulation inadequacies, floor vibrations, etc. are often causes of massive retrofit or frequent repairs over the lifespan of the facility. A unique case in the performance defect category is reserved for uses requiring specific conditions which, if not paid attention to during design and/or construction, might preclude the facility from delivering the expected service without costly adjustments.

An example of a performance defect involves the design of a concrete slab in a hospital to support a magnetic resonance imaging (MRI) machine. In this case, the machine specifications required floor rigidity ensuring no vibrational interference with the accuracy of the scans. However, the constructed floor while meeting the code requirements, did not ensure the operational requirements of the equipment. The communication disconnects between the equipment supplier and the structural engineer led to a difficult-to-remedy performance defect.

2.2. Manifestation of Defects

Defects can be further categorized as patent or latent. Patent defects are “open; manifest; evident; unsealed” (Black’s, P. 1281), in other words, obvious, which doesn’t always mean acted upon in a timely and competent manner. Conversely, latent defects are “hidden; concealed; dormant” (Black’s, P. 1026), in other words, hidden until identified through a failure of performance from operational inconvenience all the way, luckily less frequently, up to catastrophic failure. It is often the patent defect that results in investigations leading to the discovery of a potentially much more critical latent defect(s), as the latent defects, given their concealed nature, can cause significant damage to a structure and still not be identified. It is in these types of cases that rigorous engineering knowledge is needed to identify and properly characterize the situation. Once discovered, the defect and its resulting damage can be addressed.

2.3. Resulting Damage

Damage is an effect of defective design and/or construction. That is, defects in the constructed facility can lead to a consequential failure termed “damage.” While the colloquial and formally adopted word “damage” identifies a specific, singular situation that is physical in nature, the plural use of "damages" (with an s) denotes costs associated with the loss or damage (Black's, P. 466).

Damage can be categorized as either real or potential. A "real" damage is one that is an observable manifestation of distress to a structure or system. This may appear as a crack in concrete slab (Figure 4) or even partial collapse of a structure during construction (Figure 5). The real damage often results from an occurrence discussed in the section on Insurance Coverage. The potential damage is when a compromised system "awaits" the reasonably expected demand which will exceed the performance capacity of the defective system. An example of this condition could be a structural steel braced frame designed and installed to provide lateral force resistance to the building in a major seismic or wind event. However, the frame was defectively connected to the remainder of the structure thus not providing a structurally reliable load path in a critical level event. As long as there is not a maximum considered event (e.g., wind or earthquake), the fact that the structure has no competent lateral system does not result in a physical manifestation of the damage. Therefore, until the time of such occurrence, the "damage" to the structure that exists is purely in the potential performance of the structure, even if the failure could be tragic in consequence.

Figure 4. Cracking in an elevated, two-way concrete slab, which is prepared for repair using epoxy injection ports.

Figure 5. Partial collapse of a concrete structure during construction.

3. Legal/Insurance Considerations

When a defect(s) and/or damage occur at a structure, the common question asked by the building owner is: Who is going to pay to fix this? While this paper is not aimed at addressing all the ins and outs of construction defect litigation and insurance damage claims, as those can vary significantly between legal and construction insurance practices of individual jurisdictions, some fundamentals with examples are presented in the effort to provide engineering context to such questions.

3.1. Construction Defect Litigation

Defects in a constructed facility, whether caused by faulty design or construction, can lead to costly and time-consuming litigation. The process often begins when the owner/operator of a constructed facility finds some portion thereof that is not performing as it should. The involved parties may retain a scientist/engineer at the outset to determine if the failure to perform are consistent with the use specified in faulty or inadequate performance specifications or are caused by a possible defect, in which case the owner/operator can seek legal counsel to determine an appropriate path forward.

Once the legal team is in place, they may retain outside scientific/engineering firms to act as consultants and/or experts in the matter. The scientists and engineers review relevant design and construction documentation and perform site inspections to assess the conditions and to document them through photographs, measurements, layouts, and other data. Based on the collected data, analyses can be performed to inform conclusions as to the nature, extent, and severity of the purported defects. With this information, the legal team representing the owner/operator may choose to file a lawsuit as the “plaintiff” in order to recoup damages associated with the defect and any necessitated repair.

The parties named in the suit by the plaintiff are known as the “defendants.” This can include such parties as the design professionals, project managers, general contractors (GC), or sub-contractors to the GC. Each of these groups may independently (or collectively, at first) retain consulting or expert scientists/engineers to evaluate the veracity of the plaintiff’s claims.

The crux of the defect litigation is to seek compensation (damages) from those parties responsible for the defect. The damages can be used to correct the defect or provide compensation for diminution of value of the asset in question. As discussed below, any damage that results from the defective construction, however, is typically addressed through an insurance claim.

3.2. Insurance Coverage

Owners/stakeholders purchase insurance coverage for their facilities to protect themselves against the cost of repairs required after a covered peril. The coverage can include damage resulting from an occurrence and can even include losses as a result of business interruption if, for instance, the building is only partially occupiable following the event. In fact, many risk-based decision by the stakeholder are made based on the “3 D’s” – deaths, dollars, and downtime. In other words, the level of risk acceptance may come down to how many people would be injured, how much would a repair cost, and how long will my building be inoperable? A more thorough description of this type of risk-based analysis and decision making is provided in Swensen, et al. (2017).

After damage is discovered in a building (e.g., cracked drywall, water damage, missing roofing, or partial/complete collapse), the stakeholder as the “insured” files a claim against their policy with the insurance company (the “insurer”). The insurer will then engage in-house or outside adjusters and maybe architects or engineers to determine the cause of the incident (the “occurrence”) and the extent of the resulting damage. Once this information is passed to the insurer, they determine if the occurrence constitutes a covered loss and the extents of payouts to the insured, as appropriate.

An example of a common, non-coverable damage can be found in structure assessments after an earthquake. Following a seismic event (the “occurrence”), a building owner may walk around their building to survey any damage that may have occurred. Common damage in light-framed construction, for example, may include drywall cracking, inoperable doors, out-of-plumbness of the structure, and cracking of exterior façade walls. In this case, the building owner may file a claim with their insurance provider to seek recompense for this damage. The engineer retained by the insurer goes to the property and performs an inspection to determine the nature and extents of the damage. The engineer agrees with the damage to drywall and the inoperability of some doors but does not measure a total out-of-plumbness of the structure. Furthermore, they determine that the cracks in the façade walls predate the earthquake due to rounded edges (Figure 6) and the fact that plants are growing out of the cracks. The insurance company then makes a decision to pay for the interior damage but forgoes compensation for the exterior cracking, since it did not arise from the occurrence.

An interesting topic related to insurance coverage centers around the concept of “potential damage” introduced earlier. If the insurer requires an occurrence to begin the process of claim payout, then what happens if there is no damage … yet? An example of this scenario is the case where a design defect renders a structure incapable of resisting the expected design loads. Figure 7 shows a connection between a diagonal member and a gusset plate in a special concentrically braced frame (SCBF). This SCBF is part of the lateral load-resisting system for the building. The hole in the diagonal member at the gusset plate does not comply with the local building codes and renders the system unable to perform as required, moreover, and possibly more importantly, provides a week section that lacks the necessary toughness in a critical location in the structure.

Figure 6. Cracking in a brick wall. Note the rounded edges of the crack indicating it did not form recently.

Figure 7. SCBF diagonal-to-gusset plate connection with a hole left in the connection (indicated).

The fact that this design defect does not satisfy code requirements constitutes a damage to the lateral load-resisting system – that is, given a maximum considered event (e.g., earthquake, wind), the SCBF may fail prematurely. Knowing this information, the owner/stakeholder would likely believe that there is damage and seek funds from their insurance policy to cover repairs. The insurer, however, if there has not been a significant enough occurrence to *physically and observably* damage the system, may deny the claim as the damage has not yet occurred. The owner is left with a dilemma of self-financing the repair or risking injury or life loss should the maximum considered event occur.

Another example of damage that can result in a building occurs through ratcheting of deformations over time. In this scenario, a relatively innocuous deformation in a door frame can over time (and under normal and expected building deformations) lead to concentration of damage. In this case, the insurer may argue that normal and expected building deformations do not constitute an occurrence, as the e.g., wind loads were not out of the ordinary. Again, the owner is left with a dilemma where if they choose to ignore the door damage due to a lack of insurance funds, they risk operating their building with a damaged fire life-safety system necessary for safe building operation.

4. Conclusions

The paper shows how a relatively obscure deviation from the design intent or an easy to overlook construction procedure can, through extrapolation, lead to initial damage which substantially changes the resistance of the built facility to otherwise normal and expected environmental loading. The extreme cases in which the change leads to damage through ratcheting effects imposed on the initial damage caused by the defective installation or construction procedure can be, as shown in the examples, a source of tedious procedures required to assess the stages of the final damage and to allocate them to the fiscal responsibility buckets. In conclusion, the experience described herein provides a warning against superficial acceptance of the “final product”, and against relaxed inspection procedures during the construction process. The much-debated future world of AI bears promise of integration of the design intent, construction observations, and facility acceptance procedure leading to more resilient constructed facility. Such tools, like the currently available BIM used in design, will continue to evolve from academic development through experimental applications to be commonly accepted and implemented. Will the malicious ingenuity of the Parker’s law be thus made totally obsolete? Not so fast – to err is human, and even AI might have difficulty with human ingenuity.

5. Disclaimer

The views expressed herein are solely those of the authors and do not necessarily represent the position(s) of Exponent, Inc. or any other individuals therein.

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