

CHARACTERISTIC DAMAGE CONCENTRATION: A NEW DAMAGE INDEX FOR HISTORIC INTERIORS

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ABSTRACT

A crack-by-crack documentation and characterization of damage for historic interiors is often an extremely resource-intensive process resulting in either the investment of an enormous amount of resources or a low-quality record. Neither situation readily lends itself to longitudinal studies. To overcome this situation, a new damage documentation system is devised for the recording and categorization of damage for the interior spaces of historic structures. In this paper, the system is presented in the context of an early 20th century American church that was experiencing on-going damage. The structure was evaluated three times over a six-year period. The graphical results enable visualization of the progression of damage over time and an acute understanding as to its spatial distribution.

Keywords: Crack documentation, Interiors, Plaster, Computer-aided Design, Baseline condition assessment

1. INTRODUCTION

Conducting, documenting, and maintaining records of building damage in a way that is both verifiable and repeatable is extremely challenging, especially when exterior spaces that are plastered are involved. This is largely caused by the thinness of the cracking and the poor recorded images that result from using photography. Yet such records are needed in many scenarios such as to establish the evolving condition of a structure or to provide a baseline condition report prior to adjacent construction or between seismic events. What is needed is a relatively low-tech approach that can be deployed rapidly, easily, and with minimal technical training, yet takes into consideration the tensile capacity of various materials and be quantitative in nature. Furthermore, documentation of the results should exploit current standard computer systems such as computer-aided design (CAD). The intention of the paper is to introduce such a method.

2. BACKGROUND

Visual inspection alone is regularly used for pre- and post-incident preliminary building assessment in seismic [1,2] and adjacent construction [3,4] scenarios. What is most commonly used is that proposed by Burland et al. [5] to categorise building damage severity using crack size, frequency, and location (Table 1). The emphasis of that work is on crack width, and no guidance is provided as to documentation methods. Work by Laefer et al. [4] for building exteriors comparing binocular usage, close-up inspection, digital cameras, and terrestrial laser scanning showed a variety of problems and drawbacks with each method and a general inconsistency between inspectors. A much higher level of consistency for building exteriors was obtained by Clarke and Laefer [6] in their adaptation of a five-criteria set of scales. Yet in that case as well, buildings that had exterior rendering (or plastering) appeared to be particularly challenging and generated significantly less consistent results. Notably no

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such procedures have been developed explicitly for rendered exteriors or for building interiors. This paper attempts to overcome this deficit.

Table 1 Masonry Cracking Severity Scale (adapted from [5])

| Risk Category | Degree of Damage | Description of Typical Damage | Approximate Crack Width (mm) |
|---------------|------------------|---|---|
| 0 | Negligible | Hairline Cracks | |
| 1 | Very Slight | Fine cracks easily treated during normal decoration | 0.1 to 1 |
| 2 | Slight | Cracks easily filled. Several slight fractures inside building. Exterior cracks visible | 1 to 5 |
| 3 | Moderate | Cracks may require cutting out and patching. Doors and windows sticking. | 5 to 15 or a number of cracks greater than 3 |
| 4 | Severe | Extensive repair involving removal and replacement of walls, especially over doors and windows. Windows and door frames distorted. Floor slopes noticeably. | 15 to 25 but also depends on number of cracks |
| 5 | Very Severe | Major repair required involving partial or complete reconstruction. Danger of instability. | Greater than 25 but depends on number of cracks |

3. INTRODUCTION

To objectively document damage severity and facilitate meaningful quantification-based comparisons between different locations, a single characteristic damage value (CDV) accounting for crack severity and lengths, as well as the wall finish type and surface area of each room was developed, as described below. The system requires a spreadsheet in which the damage is logged by room, crack length, and maximum crack width, but no attempt is made to demarcate each damage incidence in a spatially more refined matter than by assigning it to a room's wall or ceiling.

The various wall finishes (i.e. plaster, exposed masonry, etc.) used throughout require a material's based weighting, as some are more susceptible to cracking than others. In order to overcome potential discrepancies during analysis, weightings were applied to different wall finishes (Table 2).

Table 2 Wall Finish Weights (Chosen to reflect the susceptibility to cracking and significance of the crack when considering structural health)

| Material | Plaster | Masonry (Mortar Crack) | Masonry (Block Crack) | Structural Member (i.e. concrete beam) |
|----------|---------|------------------------|-----------------------|--|
| Weight | 1 | 2 | 3 | 4 |

The severity of each crack is assessed using Table 1 and weighted using Table 2 to obtain the corrected crack severity (CCS) (Eqn 1).

$$\text{Corrected Crack Severity (CCS)} = (\text{Crack Severity} * \text{Wall Finish Weighting}) \quad \text{Eq. 1}$$

The CDV of each crack was calculated using Equation 2, and then the CDV of every crack in a single room was subtotaled to give the overall damage level within a particular room. To compare the damage level of differently sized rooms, it was necessary to correct for a room's available surface area. This is described as the Characteristic Damage Concentration (CDC) (Eqn 3).

$$\text{Characteristic Damage Value (CDV)} = (1 + \text{Corrected Crack Severity}) * (\text{Crack Length}) \quad \text{Eq. 2}$$

$$\text{Characteristic Damage Concentration (CDC)} = \Sigma(\text{CDV}) / \text{/(Approximate Room Surface Area – excluding the floor)} \quad \text{Eq. 3}$$

For presentation purposes within a CAD-based system (or even a simple set of plans), the final CDCs are scaled by $(100/\text{largest overall value})$ so that the damage values fit within a 0-100 damage scale.

4. APPLICATION

In 2004, an investigation began in Fountain, North Carolina, USA into the condition of two dozen structures that were suspected to be damaged from an adjacent quarry. Due to its significance as one of the largest and also one of the most heavily damaged buildings within the study area, the condition of the Fountain Presbyterian Church was thoroughly explored (Fig. 1). Furthermore, it is the only structure within the study area that underwent multiple, detailed inspections by the authors, agents hired by the quarry, and others authorized by the Church's congregation.



Fig. 1 Fountain Presbyterian Church

The Sanctuary portion of the Church was built of load-bearing masonry in the 1920's, with a 1960's extension of cavity construction of brick veneer over concrete masonry units to serve as an Education Building. Church records show regular maintenance expenses, except for the roof, which underwent repair in February 1970, shortly after a December 1969 chimney repair. Many subsequent roof repairs have occurred. Some in the congregation attributed problems to poor initial workmanship, but in 1980 a letter was sent to quarry refusing any further donations due to the belief that quarry blasting was causing building damage. No systematic documentation or study of the damage began until 2004.

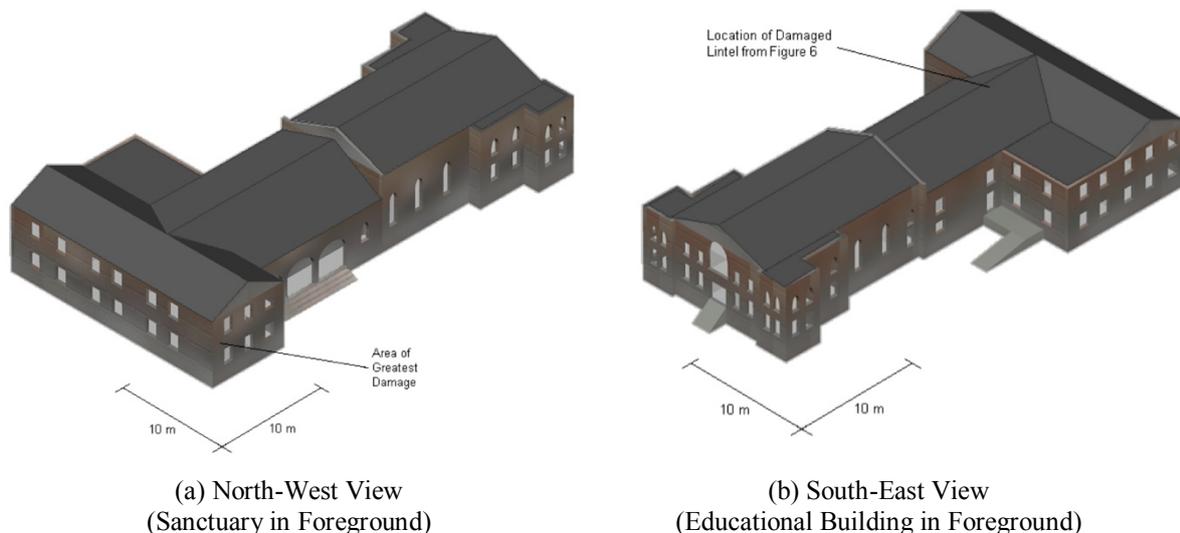


Fig. 2 AutoCAD Model of the Fountain Presbyterian Church with area of greatest damage shown

In April 2004, the only damage in the Sanctuary building was reported as water-based in the first floor room on the front left of the building. Laefer [7] stated that this “may have been the result of an opening in the roof”. In contrast, extensive damage was reported for the Education building with “(h)eavier damage on the walls nearest the quarry... the largest cracks exceeding $\frac{1}{2}$ an inch (12.5 mm)

in opening”. Laefer [7] described these cracks as “clearly structural in nature, ...will require rebuilding, and may be indicative of an imminent life-safety issue” and characterized the Education building as a seriously damaged structure. Blast-induced liquefaction was proposed as the most likely cause, despite blasting records showing peak particle velocity levels within generally considered safe limits[8.9].

The authors surveyed the Church in 2004, 2008 and 2010. Those datasets used to calculate the CDC’s for the interior damage level of all rooms. By scrutinizing the damage distribution, it is possible to discern whether the cracking is concentrated within particular areas of the building, as is typical of liquefaction induced building damage. In order to identify such patterns, the Characteristic Damage Concentrations of each room were mapped to their corresponding locations Figures 3 (a) and (b).

As shown in Figures 3 (a) and (b), mapping of building damage charts a clear progression for severity and extent, from 2004 and 2010 and may serve as a means to identify at areas of further risk. The absence of damage where the Educational building connects to the Sanctuary would not appear to support simple differential settlement between the two portions of the building due to a four-decade difference in construction periods. This escalation of damage appears to represent an ongoing problem.

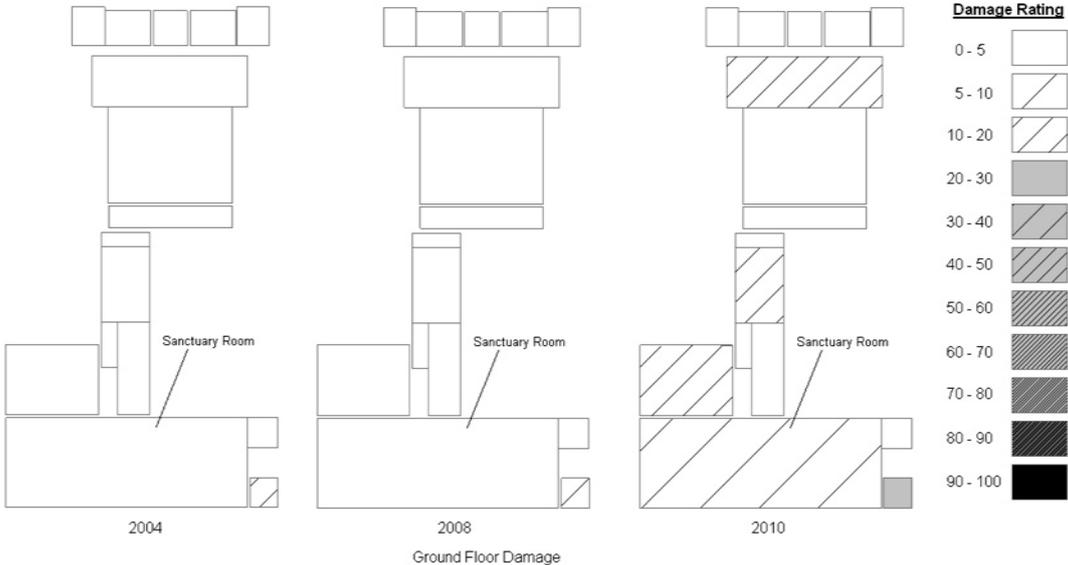


Fig. 3a Damage Distributions for the ground floor rooms from the 2004, 2008, and 2010 Surveys

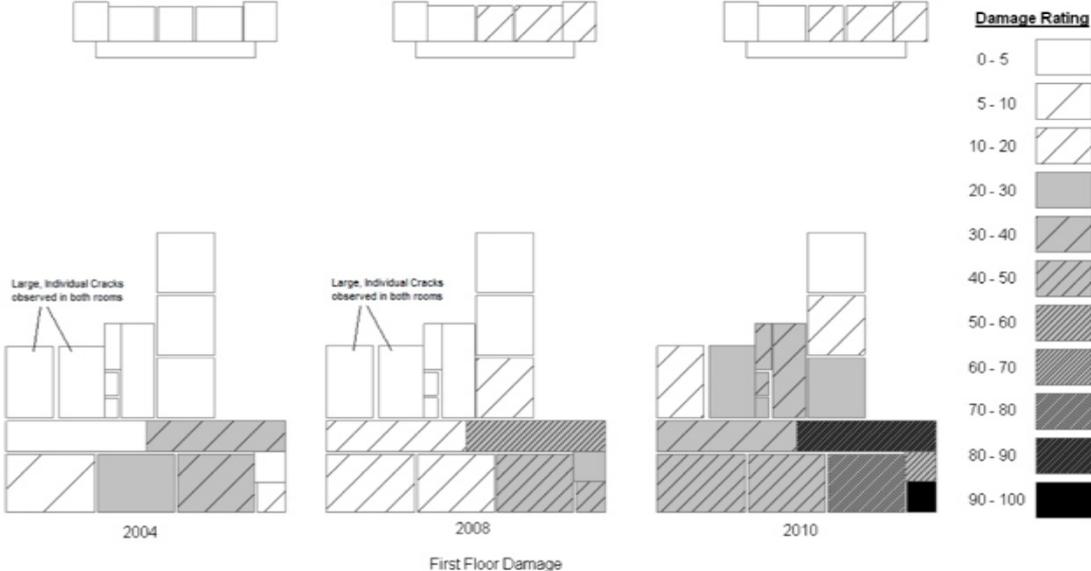


Fig. 3b Damage Distributions for the top floor rooms from the 2004, 2008, and 2010 Surveys

5. CONCLUSIONS

While the proposed system does not offer a visual depiction of each crack in terms of where it is located spatially the system offers a means to consider the building's general health in terms of interior damage at a specific point in time. This enables the use of multiple inspectors, periodic updates, and an objective, quantitatively based record.

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