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Damage Trends in Residential Structures

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Abstract

Normal environmental factors induce significant loads to houses during their design life. The majority of damage experienced is associated with footing movement and is generally caused by moisture related effects brought about by factors such as nearby vegetation and defective plumbing. Serviceability is typically affected by jammed windows and sprung floors, while other forms of damage such as cracking are frequently encountered in non-structural components such as plasterboard and masonry veneer. Correcting a defect requires not only accurate diagnosis of the root cause(s) but also careful selection of the appropriate rectification works since certain traditional techniques have proven costly and ineffective. This paper reports on the development of a unique database to capture damage information from detailed structural inspections of a large number of houses in Victoria. Data from 1000 damaged houses are summarised and presented in this paper. The database demonstrates significant trends relating damage to other parameters such as age of structure, foundation classification, vegetation, and repair costs. The database has become a useful tool for managers of large housing stock to refine their maintenance programs, assess repair techniques and plan property acquisitions.
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1. Introduction

The Victorian Office of Housing (OoH) is the government authority responsible for the provision and maintenance of approximately 77,000 residences which constitute nearly 4 per cent of the 1.9 million residences in Victoria (OoH, 2006). Although the demographics of tenants residing in public housing may be different from the majority of private homeowners, the performance of houses to various environmental loads are similar. The OoH maintains their housing stock through the Building Movement and Rectification (BMR) program. During the 2005-2006 financial year, the OoH spent approximately $96 million on maintenance of their housing stock (OoH, 2006). Periodically or at the request of a concerned tenant, a property will be inspected by an OoH field services officer. If damage to the structure is present that is deemed serious enough to require more accurate assessment an engineering consultant is engaged to conduct a thorough assessment and to provide a comprehensive inspection report including recommended remedial actions. The report is then used by the OoH to determine the appropriate course of action. To date over 40 different consulting firms have participated in this program. Although there is not a prescribed format for the report, a typical report will include the following:

- Description of the property
- Description of damage
- Recommended remedial actions
- Approximate costs of remedial actions
- Classification of damage rating

In addition to the above categories, a report is generally accompanied by supporting photographs of damage and a site sketch detailing the structure, vegetation and annotations of defects and remedial actions. There are various factors influencing the frequency of property inspections although this number has exceeded 200 annually. Over time this has generated a substantial body of data which has not been exploited for the examination of trends relating to housing performance.

The University of Melbourne has had access to detailed inspection reports from the BMR program which has provided a unique opportunity to investigate damage in houses due to environmental loads. The primary aims of this research project are to:

- Develop a Knowledge Management System (KMS) to store data from BMR inspection reports electronically in an efficient and accurate manner.
- Populate the KMS with inspection reports from the BMR program.
- Identify damage trends common to residential structures and investigate the adequacy of remedial actions recommended to rectify damage.

The principal deliverable from this research project has been a Knowledge Management System which has been developed to store data from the BMR program. A pilot study of 30 inspection reports was undertaken to determine the requirements of the KMS. It was established that in total, the KMS would accommodate 107 fields for data entry and a browser based user interface. A more comprehensive description is provided in Heath et al (2006). Following the completion of
programming tasks for the KMS, data entry commenced requiring the services of three data entry people to transfer all relevant data from the reports to the KMS. At the conclusion of data entry 1008 reports had been entered for 1000 different properties. Analysis of data in the KMS has been completed and various damage trends identified. This paper focuses on trends relating to remedial actions recommended by consultants.

2. Literature Review

Damage to residential structures due to environmental loads and consequential repair work is a global issue. Page and Murray (1996) report on a survey of 501 residential properties in East Midlands, UK, identifying 844 specific structural defects. The survey revealed 63.9% of defects were attributed to ground movement, 22.4% to the superstructure and 13.7% were associated with material defects. Sorensen and Tasker (1976) list the principal causes of movements in foundations to be settlement, moisture variation in plastic soils, instability of sloping ground, and miscellaneous factors. Page (2001) noted differential settlement may result from non-uniform consolidation, the existence of variable ground beneath the structure and/or a local failure of the foundation. Crilly (2001) states soil shrinkage and swelling is the greatest contributor to foundation related damage.

The most common technique employed to reduce or eliminate damaging movement in a house is underpinning. Early guidance on the principles and applications of underpinning were provided by Hunter (1952) who described underpinning as the art of providing new foundations under an existing structure without compromising stability. The purpose of underpinning is to arrest progressive movement (Hunt et al, 1991). Two of the main factors driving underpinning in the UK have been insurance policies seeking a final solution and surveyors and engineers protecting their professional indemnity insurance (Catt, 1993; Anumba and Rafiq, 1995; Dickinson and Thornton, 2004). Cover for subsidence damage by insurance agencies in the UK is unique in this respect. Freeman et al (1994) relate the necessity to undertake underpinning to crack width, suggesting the procedure becomes a cost-effective means of preventing further damage when cracks between 5 – 15mm are present and the movement has been identified as progressive. The tendency to associate the requirement of underpinning to level of damage was observed by Crilly (2001) based upon the analysis of a subsidence database including records from 484 subsidence claims. A substantially greater percentage of properties receiving remedial underpinning were observed when crack widths recorded were greater than 5mm. Wilkin and Baggot (1993) investigated the relationship between 11 variables and the decision to underpin based upon 282 cases of underpinning recorded in Essex, UK. The analysis concluded the greatest influence on selecting underpinning was crack size. Hunt et al (1991) support the view that there has been much unnecessary remedial underpinning claiming widespread ignorance of causes of damage and of the ability of buildings to tolerate movements. They add that unsuccessful underpinning projects have resulted from poor workmanship, inappropriate design, lack of heave potential and insufficient depth to avoid future desiccating effects of nearby trees. This sentiment is supported by Grahame (1973) who warns that underpinning may further increase remedial costs since it does not provide cracks with the opportunity to close. Biddle (1998) notes that in the majority of cases underpinning is avoidable when dealing with seasonal movements and states alternative cheaper methods to be more appropriate. There are numerous other satisfactory alternatives to performing underpinning although they are beyond the scope of this paper.
3. Profile of Database Population

The OoH manages properties that vary from recently constructed to some that are more than 100 years of age. Site conditions including site class and climatic category vary as do type of construction and the year a property has been inspected. Figures 1 and 2 depict important characteristics relating to the profile of properties included in the KMS and the entire OoH housing stock.

Figure 2 depicts the distribution of year of construction for properties in the KMS and for the entire OoH housing stock. Approximately 91% of the reported year of construction of all inspected properties lie between 1940 – 1999 inclusive, with the greatest representation in house construction occurring within the 1950 – 1959 category. It may also be seen that properties constructed in the periods of 1930-1949 and 1960-1969 are over-represented in the database. In contrast, properties having their year of construction after 1984 are under-represented. This potentially suggests properties between 40-50 years of age and 60+ years are poorer performing properties. Equally, houses constructed after 1984 have performed much better with a substantial drop in inspections relative to database population for the respective periods.

Light-framed properties including brick veneer account for 72% of houses in the KMS while cavity construction represents 21% of all properties. Where site class is reported according to AS2870-1996, 62% of properties are situated on class H sites while 31% are located on class M sites. The remaining 7% of properties are composed of class A, S, E and P site classifications.

Figure 2 contains the distribution of properties in the KMS constructed prior to and post implementation of AS2870-1996. It is noted there is very little reduction (1.9%) in representation within class M, compared with a more noticeable 11.2% reduction for houses situated on class H sites suggesting a marginal improvement in the performance of houses designed for this class.

![Graph showing age profile comparison](image)

*Figure 1: Comparison between age profile of database population and entire OoH housing stock.*
4. Remedial Action Recommendations

In order to correct damage to the dwelling the consultant recommends the appropriate remedial work be undertaken to eliminate or minimise the effects of the identified cause(s) of damage and to repair the damage. A summary of recommended remedial work is provided below based upon the 1008 inspection reports.

4.1 House Exterior

Wall cladding attracted the greatest number of exterior remedial actions accounting for 29.0% (refer to Figure 3). The second greatest contributor to total remedial costs was the miscellaneous category at 23.5%, followed by installation of perimeter strips around the house (21.7%). The representation of the miscellaneous category in house exterior actions is attributed to the diversity of possible actions which prohibited this category from being broken down further. The patch/paint and roof cladding categories collectively account for only 14% of exterior remedial actions. Underpinning work accounted for 86.3% of recommended footing work, although footing remedial action accounted for only 11.9% of all house exterior remedial actions (refer to Figure 3).

One of the key remedial actions requiring investigation is underpinning, owing to the frequency of recommendation and substantial costs to complete the work. Of the 1008 property inspections performed, one in three inspections recommended underpinning. In order to understand the mechanisms driving this action the relationship between underpinning and a number of key factors are considered. Figure 4 demonstrates a trend between the severity of damage and frequency of recommending underpinning works. The percentage of houses that have a maximum crack width of 5mm is 23.7% compared to 32.2% for houses with a maximum crack width of 15mm. Houses having a maximum crack width between 15-25mm were most frequently nominated for underpinning (52.6%) and similarly, the percentage of houses recommended for underpinning having crack widths greater than 25mm was 48.5%. Hence, one in four houses with maximum crack widths of less than 5mm are recommended for underpinning compared to one in two houses where the maximum crack width is at least equal to 15mm.

A comparison of properties nominated for underpinning with site class shows that nearly one third (31.5%) of damaged properties situated on class H sites are recommended to be underpinned compared with just under one fifth (18.9%) of damaged properties situated on class M (refer to Figure 5(a)). The introduction of revised residential footing standards in 1986 provides a poignant...
point for further investigation. From Figure 5(b) it may be seen that there is no difference in the number of prescribed underpinning exercises for houses located on class M sites prior to or post AS2870-1986. In contrast, houses constructed after implementation of AS2870-1986 are less frequently prescribed underpinning relative to those constructed prior to this time when situated on class H sites. However, the houses encompassed in the pre AS2870-1986 period account for a wide range of construction styles through a period of more than 85 years. There are too few records of underpinning for houses situated on the remaining site classes to draw conclusions on trends for underpinning recommendation. By comparing the percentage of all underpinning work undertaken on different site classes as shown in Figure 6, it can be seen that minor underpinning works are favoured on class M sites compared with major underpinning works being favoured on class H sites.

An investigation of the proportion of properties recommended for underpinning and nominated causes of damage in these properties it is possible to establish the principal mechanisms leading to the recommendation for underpinning. Figure 7 shows vegetation dominates the major identified causes of damage (31.9%) followed by climatic conditions (21.3%), site conditions (17.5%) and leaking services (12.3%). Figure 7 shows factors influencing soil moisture amount to 83% of all identified causes of damage, while damage due to shallow footings (6.6%) is also directly related to variations in soil moisture.

![Figure 5](image.png)

**Figure 5:** Percentage of database population recommended for underpinning according to AS2870 site class for (a) all underpinning and (b) pre and post AS2870-1986. Figures in brackets indicate the number of houses in each category.
4.2 House Interior

Figure 8 shows the majority of internal remedial actions involve patch/paint work (48.7%) while flooring work constitutes 28.5%. Most houses requiring patch/paint works require large areas to be attended to (67.7%) whereas only 12.4% of patch/paint work is for small areas and the remaining do not have an area listed. More than half of floors requiring attention needed re-levelling while more extensive stump replacement was recommended in 27.7% of cases as shown in Figure 9.
4.3 Plumbing

Figure 10 shows that the above and below ground components of the stormwater system collectively account for 60.6% of all plumbing remedial actions. When suspicions relating to plumbing leaks occur, a pressure and/or visual test is recommended which accounts for 21.1% of all plumbing remedial actions which has the potential for follow-up action subject to the outcome of testing. Remedial actions to the sewage system and mains water combined are 8.5% where miscellaneous items amount to 9.2%. The majority of plumbing categories mainly require minor maintenance except the below ground stormwater system which is dominated by significant/immediate repair.

5. Recommendations for Enhancements and Future Studies

The structure and content of the existing KMS has largely been dictated by the current process of reporting for the BMR program. However, there are a number of improvements possible for the KMS. One main area of interest is effectiveness of remedial actions. There is generally a broad scope of remedial actions suggested in each report and in certain instances, for the removal of mechanisms that are driving damage. The selection of each remedial action is based upon the consultant’s experience and in the majority of cases there is no measure of effectiveness of specified remedial actions unless damage returns. Remedial actions such as underpinning are frequently prescribed and are expensive to perform. Other frequently performed actions such as vegetation removal may significantly affect the amenity of a site and may be suggested based upon a cursory visual inspection rather than identification and evidence of tree root activity.

Other avenues for future exploration include the implementation of a GIS for the development of predictive tools and the adoption of an in-field platform to operate the KMS to avoid secondary data entry. A possible extension to the KMS structure is to include provisions for logging detailed data from geotechnical investigations.

Figure 10: Percentage of actions recommended in the plumbing category.
6. Conclusions

The Victorian OoH manages more than 77,000 properties requiring regular inspections and rectification works through the Building Movement and Rectification program. The KMS has been developed for the recording and analysis of defects and remedial actions which has been used to identify various trends. The KMS platform consists of a database accessed by a user-friendly browser based software enabling data entry and export for analysis in spreadsheet applications.

Globally, significant damage is experienced by residential structures due to foundation related movement. One of the most expensive measures frequently employed to arrest movement is underpinning. However, numerous studies on underpinning in the UK suggest this technique has been frequently incorrectly prescribed largely due to misdiagnosis. The procedure may lead to unnecessary escalations in cost, failure to adequately arrest future movement and in some cases exacerbate damage. Involvement in the BMR program has provided the opportunity to investigate trends in the prescription of remedial works and the opportunity for assessment of effectiveness of remedial actions.

Relative to the entire OoH housing stock the profile of the KMS population is skewed towards older properties with the majority of properties having a light-framed structure and situated on moderately to highly reactive soils in climatic category 3 as per AS2870-1996. Only a moderate reduction in the representation of houses situated on class M and H soils was observed within the database population for construction after the implementation of AS2870-1986.

Repair work to wall cladding is the greatest contributor to the number of remedial actions performed on house exteriors while patch/paint work is most frequently performed to house interiors. On average one in three properties are recommended for underpinning, with an increase in the proportion of houses being recommended for underpinning with increasing maximum recorded crack width. Houses located on class M sites are favoured to have minor underpinning works compared with major underpinning being more prominent for class H sites. Implementation of AS2870-1986 has not had an appreciable influence on the proportion of underpinning performed on class M sites although a 16% reduction is observed for dwellings on class H sites for properties in the KMS. Vegetation is the most frequently correlated cause of damage with underpinning works.

Based on the trends presented, inappropriate vegetation and defective stormwater systems cause the great majority of damage. These two specific areas could be addressed through a preventative maintenance program.

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8. References