Observations on Tornado Damage to Residential Structures in Bendigo

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Introduction

Post-disaster data collection is a vital component of natural hazard assessment model development. Surveys of this type provide insights into the vulnerabilities of different building types to various hazards and may, in some instances, furnish valuable calibration data for verifying vulnerability models. The Risk Research Group of Geoscience Australia (GA) is presently developing and adapting multi-hazard vulnerability models for Australian structures that will be ultimately utilised in a national risk assessment methodology. As part of the model development GA has carried out a number of post-disaster reconnaissance exercises including a systematic study of the wind damage caused by the May 2003 Bendigo tornado event. Residential structures of various types and ages were surveyed and contemporary brick veneer construction was found to represent the largest single group. The survey findings for this type of residential construction, along with an associated damage costing exercise that followed, are herein described.

The Tornado Event Description

The tornado occurred around 6:00 pm Eastern Australian Time on Sunday May 18, 2003 and lasted about 1 to 3 minutes. From eyewitness interviews it is estimated that the tornado traversed the suburb of Eaglehawk at a speed of approximately 65 km/hr with a counter-clockwise spin. The tornado cut a 7 km long and sometimes discontinuous path across the city in a generally easterly direction with the greatest concentration of damage found in the suburbs of Eaglehawk and California Gully. The tornado was not forecast by the Bureau of Meteorology (BoM) and no specific warnings were issued. Fortunately there were no reported injuries despite the generation of much airbourne debris through the loss of many roofs and fences.

Wind Speed Estimation by BoM

About 10 am on the morning of the 19th May officers from the Victorian Severe Weather Section of the Bureau of Meteorology (BoM) made a visit to the affected area. They collected evidence of the wind speed using the phenomena described in the tornado intensity scale established by Fujita and Pearson. The BoM concluded that this tornado had a Fujita intensity of F1 with some localities experiencing an intensity of F2. The wind speeds corresponding to these two intensities are 140 km/hr and 180 km/hr, respectively. While the phenomena that were studied for wind speed estimation included the degree of residential damage, other vulnerability independent evidence was collected. This included a caravan being blown downwind about 150 metres and coming to rest upside-down, a garage door carried about 4 km by the wind, a wooden stick being pushed down into the ground to a depth of 10 to 20cm, and the partial debarking of a paperbark tree.

Survey Exercise Description

The GA survey team arrived on the 3rd June some 16 days after the tornado event and data was collected over a period of three days. The survey team comprised a structural engineer, a numerical modeller and a geographical information system (GIS) specialist. From a preliminary reconnaissance of the area that was facilitated by an officer from the City of Greater Bendigo a survey corridor 150 m wide was identified through the two worst affected suburbs. All homes along a 1.4 km long corridor were surveyed utilising palm top computers, GPS and digital cameras. Figure 1 shows the corridor with the initial estimate of roof damage represented by gradations in colour. The physical damage observed were broadly quantified and structural failures were studied where access permitted. In total 180 homes were surveyed as summarised in Table 1 and 64 of these were found to have sustained some degree of damage.

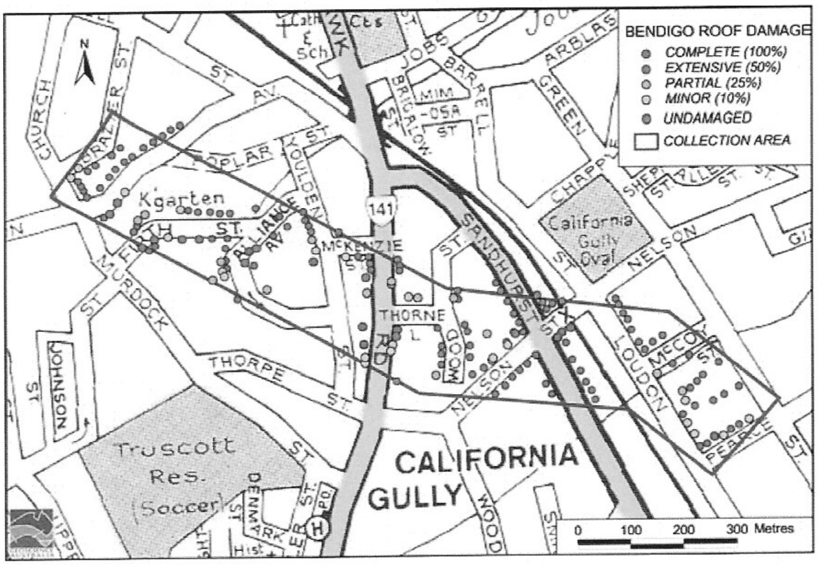

Figure 1:- Tornado damage corridor surveyed from 3rd to 5th June 2003.

Table 1:- Age and construction composition of surveyed residences.

Wall Type	Roof Type	Older Than 1931	1931 to 1960	1961 to 1980	1981 to 2003
Brick Veneer	**Tile**			9	35
Brick Veneer	**Metal**				73
Weather-board	**Tile**		12	1	
Weather-board	**Metal**	7	28	3	2
Double Brick	**Tile**		5		
Other	**Tile**			1	
Other	**Metal**	2	1		
Stone	**Metal**	1			
Totals		**10**	**46**	**14**	**110**

Observations on Structural Vulnerability

Many relatively new residential structures (less than 20yrs of age) were damaged in the tornado event. The surveyed suburbs were built in gently rolling terrain located on the city fringe. In terms of AS 4055-1992 the ultimate design wind speed would have been in the range 34 m/s to 40 m/s depending on the shielding and topography. From a comparison of the BoM estimates of actual wind speed (40 m/s to 50 m/s) it was concluded that structures experienced wind pressures at or above their ultimate design load levels. When this is coupling with the construction variability found in largely non-engineered residential construction, structural damage could be expected and was observed. Site inspections sought to ascertain where structural deficiencies had contributed to the observed damage. Some observations on structural vulnerability are discussed under separate headings below:

Sheeting / Tiling Fixtures

In some instances metal sheeting was lost leaving roof purlins in place. Observations revealed that some sheeting had not been fixed in accordance with the Manufacturer's instructions. Smaller fastener spacings at roof edges and ridges where localised wind vortexes increase suction pressures were sometimes absent.

Roof tiles were found locally "plucked" from some roofs. For new construction in areas of low wind speed (as is Bendigo) the standard AS 2050-1995 requires every second row of tiles to be mechanically fastened to battens. Once the wind suction exceeded both the tile self weight and inter-tile interlock non-affixed tiles could be lifted out. This failure mode was observed in roofs of all ages but was more noticeable with older homes having more poorly affixed roof tiling.

Purlin Loss

The most common roof sheeting loss observed was that associated with the failure of the purlin to rafter connection. Nails securing the affected purlins withdrew and the sheeting was lost with the purlins still attached. Inadequate nail size and/or penetration into rafters may have contributed to this.

Rafter/Truss to Top Plate Connection

Loss of trusses due to a failure of the truss to wall framing connection was observed in a number of instances. Inspections of the remaining trusses sometimes revealed that the builder had skew nailed the connection rather than using a proprietary connector having several times the capacity (eg Pryda "Multigrips"). In other instances connectors were present but were found to be incorrectly installed.

Top Plate to Double Brick Wall Connection

Roof connections to double brickwork usually entails the embedment of metal straps into a wall mortar course and the nailing of the opposite strap end to a timber plate laid across the top of the brickwork. Two garage roofs appeared to have been lost as a result of poor wall tie details.

Repair Costing of Contemporary Brick Veneer Structures

Wind vulnerability relationships typically relate the incident wind speed to the financial loss incurred expressed as a percentage of the building replacement value. Insurance claim data often provides the basis for such curves requiring careful adjustment for a number of factors that can distort the data. These factors include under-insurance, post disaster inflation, fraudulent claiming of pre-existing damage as wind damage, and the complexity of separating out damage repair costs associated with often more vulnerable peripheral structures (fences, sheds). Full replacement costs for the surveyed contemporary brick veneer homes were determined using a suite of residential cost models developed for GA by Cordells. Detached structures on the residential properties were excluded. House floor areas were ascertained using both aerial photography and building permit data supplied by the City of Greater Bendigo. Corresponding repair costs were obtained either directly from detailed quotes prepared by a large building company, or were derived from costings performed by GA using the same company's costing structure.

Verification Data Comparisons

The spatial distribution of the sustained financial losses permitted the tornado path to be more precisely defined. The corridor width that experienced the strong winds varied and the counter-clockwise spin of the tornado was particularly apparent in the Eaglehawk area (refer Figure 2). Within the tornado path 80 brick veneer homes were located with 37 damaged. Despite the small size of the data set the results were aggregated to obtain a single verification data point. Expressing the losses on a population basis the mean wind speed of approximately 45 m/s resulted in a mean loss of 4.7 % of the combined replacement value of the homes exposed.

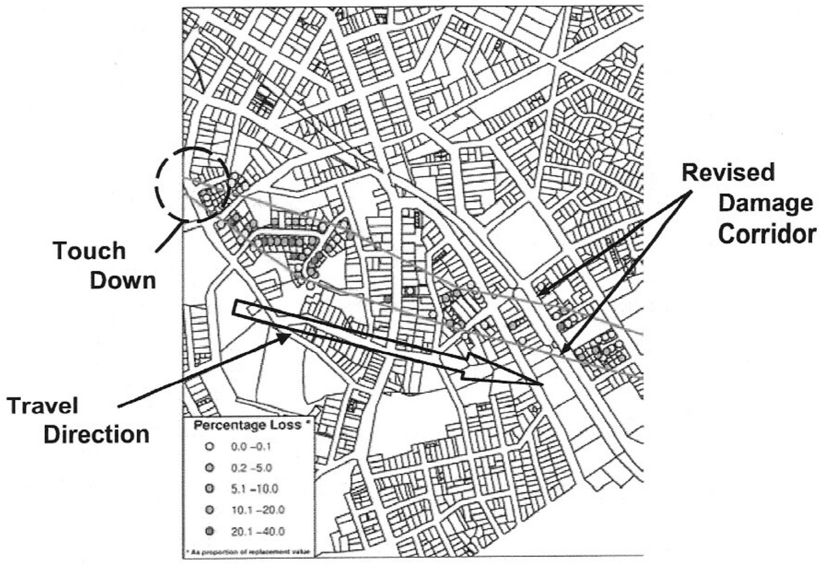

Figure 2:- Refined tornado damage corridor and damage levels.

Several residential vulnerability curves are presented in the literature. The two curves proposed by George Walker for North Queensland residences are shown in Figure 3. Also shown in the figure is a curve developed by Sill for pre-1992 U.S. homes based on hurricane damage claims. The data point obtained from the Bendigo survey is further presented and lies very close to both the pre-1980 George Walker curve and that proposed by Sill.

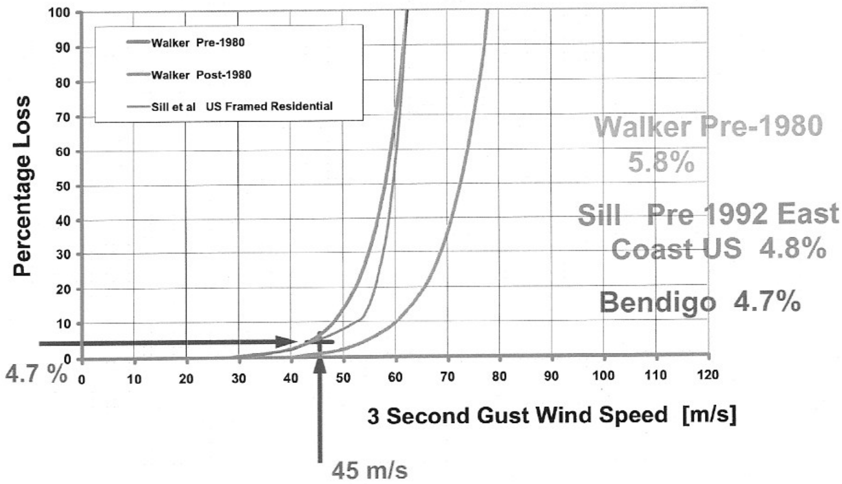

Figure 3:- Comparison of aggregated Bendigo damage to published vulnerability curves.

Summary

The wind speeds associated with the Bendigo tornado event exceeded the design ultimate wind speeds for many residential buildings. Structural damage to some homes could be anticipated and was observed. The vulnerability observations revealed that inappropriate connection details did in some instances contribute to the observed damage.

The single verification data point suggests that George Walker's pre-1980 curve for North Queensland structures may also be representative of non-cyclonic brick veneer residential construction. However the significant limitations of data set size and the non-uniform nature of the wind field make the drawing of any firm conclusions difficult.