Building Floor Levels and Verticality Surveys – Data Capture and Presentation Using a Canterbury Example.

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SUMMARY

This paper presents personal experiences of the Canterbury earthquake, before reviewing some of the field data capture and presentation practices that have been adopted. Specific focus is given to surveys of buildings and structures that measure vertical condition and floor levels. This paper presents challenges, considerations and recommendations for field practice, including equipment selection and measurement procedures, and data presentation, developed from experiences of carrying out such surveys in Christchurch over the past five and a half years.

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1. INTRODUCTION

The earthquakes of the last five and a half years in Christchurch and its surrounds have had a significant impact on the lives, both personal and professional, of Surveyors in the region. This paper focusses on some of the experiences of one surveyor firstly at the time of the first major quakes that the region felt, and then during the following years as the workload changed to account for some of the different and less familiar survey types.

Canterbury Surveyors have been faced with many difficult, unique and never-before-encountered challenges. These have included monitoring of building rubble during the immediate rescue and recovery operations, measurement and assessment of precariously damaged buildings, land deformation monitoring, building floor levels and vertical condition surveys, survey mark protection surveys, along with a great variety of other surveys to support recovery, rebuild, repair, renovation and new construction across the wider region.

The experiences of each surveying consultancy operating out of Canterbury over the last five years will have varied considerably based on, among other things, their existing client bases, specific projects encountered and core business of each firm. This paper is not intended to be an authoritative manual, but rather a collection of experiences and considerations that one surveying firm has developed since the quakes, specifically in the areas of capture and presentation of structure vertical condition and floor level survey data.

2. PERSONAL EARTHQUAKE EXPERIENCES

2.1 September 2010

The first of the Canterbury earthquakes began for us all in the early hours of Saturday 4 September 2010, with a quake of magnitude 7.1 (Geonet). While the epicentre was located within 40 kilometres of the Christchurch central business district, and many buildings suffered moderate-to-major damage, the amazing thing about this quake was that no one lost their lives to this quake.

A few significant aftershocks from this first quake also captured our attention, though similarly did little further damage.

2.2 22 February 2011

It was the quake at 12:51pm, 22 February 2011 that was the most memorable. I was sitting at my desk, thirteen floors up in the then Price Waterhouse Coopers building, eating my lunch, when this magnitude 6.3 quake hit (Geonet). Without even a thought, I found myself crouched under my desk, watching my filing cabinet drawers roll all the way out and then all the way back in again as the building swayed from side to side.

The first thing I recall seeing as I looked out the window was the collapsed Pyne Gould Corporation (PGC) building– a four-storey building that had previously been an integral part of my view, flattened down to a fraction of its size. (Figure 1) At the same time, I saw a great cloud of dust rise from the central city and I knew that this would be catastrophic.

Figure 1: Collapsed PGC Building. Source: Fox and Associates.

Another big quake hit while I walked home, as well as several smaller ones. Each time, I'd hear falling masonry already loosened from the big one. Walking past some local shops, some people had already found a digger and were clearing rubble from a shop-front while others shouted into the building, calling for a response from trapped workmates.

Figure 2: The House Next Door. Source: P. Dewar.

Arriving home, my wife had injured herself during the quake while running through our house to be with our daughter – bad and painful bruising. Many things were thrown around in our house – cupboards shaken open, crockery broken, and fallen furniture. The house next door, thankfully vacant at the time, had practically collapsed. (Figure 2) For the next few weeks my young family and I based ourselves away from the city – with no running water, electricity or sewage service, it would have been very difficult for us, with a 20 month old daughter and also expecting our second child.

A week following the quake, Fox and Associates was up and running again, operating from the living room of one of our Directors. We were thankfully able to extract much of our key equipment from our offices within that first week, and so we were able to begin work in the new, quake-destroyed city in which we now found ourselves. For three weeks we each had half a trestle table as our work space and it was certainly cosy sharing an office with up to eight others, along with a server, field equipment and chargers, and the poor family members whose living room had been replaced with a Surveying Firm.

There was a great rush of demand for safe undamaged office space but Fox and Associates were able to come upon some suitable office space, which served us well for three and a half years, before we moved into long-term offices in late 2014.

A great many earthquakes followed over the two years that followed this. Some of these caused further damage to land, buildings and infrastructure; however the main ongoing impact of these quakes was the further stress to the lives of many people – triggering often raw memories of the recent major quakes, along with many persisting personal and property difficulties.

3. BUILDING ASSESSMENT SURVEYS

3.1 The Initial Challenges

As soon as we were able to begin work again, with our field equipment, computers, vehicles and staff back on board, demand was high to measure buildings, tanks and many other structures; to check their vertical condition, floor dislevelment, and to establish monitoring regimes to check for ongoing movement.

It is likely that many Christchurch Surveyors were in a very similar predicament: This was a completely different set of work in which there was little first-hand experience. Christchurch Surveyors had seldom been required to check the vertical condition of buildings or floor dislevelment and certainly not on the scale that they were all encountering. There was little in the way of established professional best-practice guidance in place – neither written down nor inherited from senior surveyors as tribal knowledge – to lead them in one consistent direction. This situation required them to newly establish principles of field data capture, office processing and data presentation on-the-fly; and all this in a very dynamic environment – ongoing earthquakes, no reliable local survey control marks and a mountain of work ahead.

3.2 Field Data Capture

3.2.1 <u>Structure Vertical Condition</u>

The purpose of a structure vertical condition survey is to determine the amount of vertical deviation of a building or structure. A great many buildings across Christchurch have been surveyed for vertical condition since the quakes, along with many other significant structures such as tanks, communication towers, pylons have also been similarly checked.

While certainly not the case for all applications, the bulk of these surveys have been undertaken on buildings, and also to the external façade of the buildings. Before measurements to the external façade of a building can be considered useful to the damage assessment of a building, a few assumptions must be made, such as:

- That the building was constructed vertical,
- Prior to sustaining any quake damage it was not subjected to any settlement,
- The façade has a direct linear (or known) relationship to the core structure of the building,
- The façade is smooth – not roughcast or irregular stone/brick work – and can be easily and reliably measured at required positions,
- The methods and accuracy of the measurements over the height of the building will be sufficient to draw useful conclusions on the vertical condition of the building (sometimes difficult to assert in the case of single storey buildings with rough-cast cladding)

There are a number of methods that could be used to measure building vertical condition, such as:

- Using a builder's spirit level held up against the significant structural walls of the building and measuring offsets from vertical. With a computed lean value (millimetres per metre) and a known wall height, a full approximate wall lean value may be extrapolated. Similar observations could be made to surfaces assumed to be level prior to the quakes, such as windowsills or door frames.
- A variety of other laser setting-out tools, as often employed by builders during construction, in combination with offset measurements made from vertical at top and bottom of wall, to derive a total lean value.
- Reflector-less total station measurements to multiple positions up the face of the wall, structure or building corner. Subsequent comparison of the position and height of measured positions provides the vertical condition of the measured building face or corner. Additional measurements may be taken at more frequent intervals to assess variations in lean over the height of the structure.
- Laser scanning the object, or portions thereof, and using the resultant point cloud to model best-fit surfaces or line work to the structures and their deviations from intended surface.

Each of these techniques, along with any number of other variations to them, has their valid uses. The decision to choose any one of them is greatly affected by the scale of the work involved, the outcomes expected by the end-users of the measurement data and the availability of equipment.

In personal experience, reflector-less total station measurements have been used most commonly for structural vertical condition surveys. The advantages of using this equipment include:

- Its availability for immediate deployment to site
- Scalability of amount of measurement, depending on the measurement situation
- Remote measurement allows for safe, quick data capture
- Straightforward data capture and reduction process

On some occasions where larger or more complex structures have been involved and equipment has been available, laser scanner equipment has also been used. While this has the ability to capture vast amounts of data, it requires a greater level of experience in capturing and processing the data to extract sensible reliable results. The results also need to be reduced and presented in such a manner that can easily be applied to all end uses.

There are also cases where the simple methods of builder's spirit level and tape-measured offsets are warranted. Such cases are most commonly used when assessing the interior walls of single-storey buildings. Care needs to be taken when using a builder's level, that the wall is suitable for measurement: A wall may vary considerably over its height, and the measurement cannot necessarily account for all the variation. Commonly the measurement of lean of a single building wall will be used to assist in assessing (by others) the structural condition of a building – for internal walls, the best assessment of this is between the very bottom and very top of the wall. Without a straight-edge of the appropriate size, or a suitably sized spirit level, this method can only measure a portion of the wall, and therefore is not the best estimate of wall vertical condition.

3.2.2 Floor Level Measurement

Floor level measurement, even more so than vertical condition measurement, has been a widespread tool used in the building assessment process following the earthquakes. Floor levels can often provide greater detail of building foundation and structure condition, especially in the case of low-rise and single storey dwellings. Christchurch has seen a great variety in floor measurement techniques, carried out by operators with greatly varying degrees of training and experience.

A number of different methods of floor level measurement have been employed. Choice of method has depended on the situation, equipment available and familiarities of the operators. Some of the more commonly adopted methods have been:

- Level and staff measurement
- Hydrostatic level measurement
- Total station measurement
- Laser scanned point cloud each at positions across the floor.

Whatever the method chosen, there are a number of considerations that the surveyor must account for in order to obtain the most reliable results, get the best use of the equipment and make the best assessment of the current state of the floor level.

The primary factor that should determine choice of equipment is its ability to meet the required accuracy standard and specifications for the survey. Good knowledge is therefore needed of the working accuracies of the equipment, the accuracy requirements as stated by the client and ease of data acquisition – it may be more efficient to capture floor levels with a digital precise level to a greater accuracy than is required by client.

All floor level measurements need to be carried out by suitably qualified, trained and experienced personnel. Personnel should be familiar with concepts of evaluating error sources, incorporating error checks into on-site workflow and understanding the accuracies of data outputs associated with any equipment that they are using. Operation manuals for less familiar equipment can also provide key guidelines on operating the equipment to ensure the most accurate and efficient results.

Thicknesses of all floor coverings need to be assessed and recorded at time of survey. This ensures that all levels can be suitably reduced to a common reference surface and are therefore comparable across the building.

Where discrete floor points are being measured, careful consideration is needed regarding the locations of floor levels measurements. These locations should be selected at a suitable density and at positions to best represent the key structural elements of the building. This is especially important for multi-storey buildings. Where the project allows, this should be undertaken in consultation with structural engineers or other such consultants.

3.3 Data Presentation

While the field measurement component of building assessment surveys provides a basis for certainty that the data is accurate and has been reliably collected, it is the presentation and delivered form of the data that the end-user sees. In addition to accurate data capture, the Surveyor's role also to present it to the client in a manner that will enable all end users to readily understand and digest the information presented.

For a particular project, the principal client may be a private owner, structural engineer, insurance company, loss adjuster, quantity survey or other party. Regardless of the principal client, however, the nature of the data presented and the situation into which the data will be delivered, means that any one of those parties may end up reviewing the data – regardless of who is paying the bill. Similarly, if the data is presented ambiguously, any one of those parties could very well request clarification of the delivered product, notwithstanding that another party may be the direct client.

3.3.1 Building Vertical Condition Data Presentation

The vertical condition of buildings can be difficult to present in a manner that is understandable. Whether it is in the form of a plan showing lean vector arrows, separate plan and elevation views of walls, a separate lean table, or another means again, it can be challenging to depict the measured data in a way that clearly represents the condition of the structure.

Typically where the building is three storeys or less, a single vector arrow with an accompanying label can clearly depict the data. The arrow line can be scaled, with the length of the arrow line representing the overall lean distance of the structure and arrow showing the direction of tilt from bottom to top. The label can assist by displaying detail about the vector – an overall lean value (horizontal distance that the structure leans), a direction of lean and a relative lean value (millimetres lean per metre height) or other metadata. This allows structures to be readily and visibly compared in plan view across the subject site. See Figure 3.

Where data is displayed in this manner, the measurements made to the top and bottom of the structures are the most significant to the final delivered data. Any intermediate measurements made partway up the building act primarily as checks to the data and only used if the upper or lower data is discovered to contain errors.

The main advantage of this graphical vector arrow method for displaying structure lean data is that it is straightforward to interpret from a single plan view. Disadvantages come where structures increase in height, the building can no longer be assumed as linear and the intermediate measurements therefore become more significant. The assessment of building warp or non-linear lean is not easily displayed in this manner, so for larger buildings, other options must be considered for data presentation.

Where discrete total station measurements are made across multiple levels of a structure or a significant elevation, data can also be presented with the use of elevation views. For each building corner, and in both elevation directions for that corner, measurements are projected onto an elevation view. The resulting data is a view that depicts the axial lean at the measured building line.

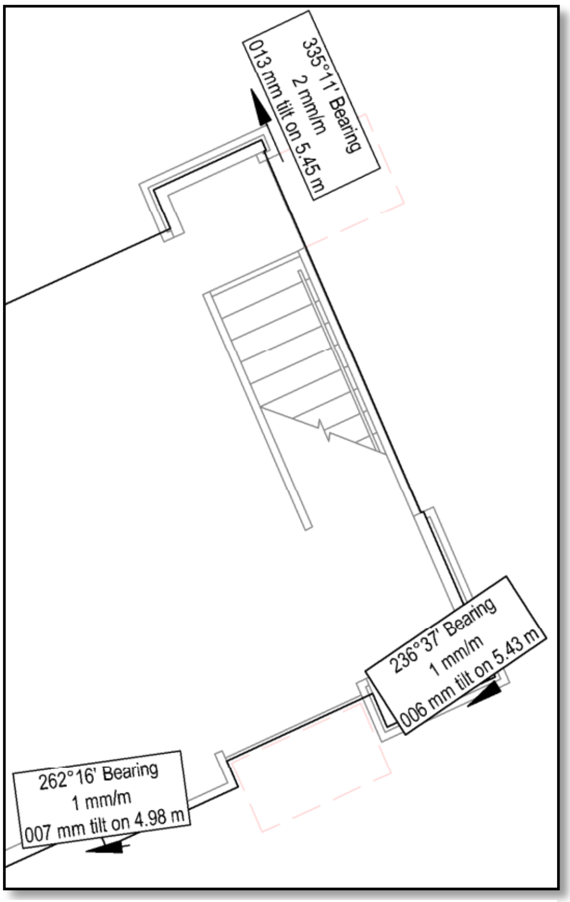

Figure 3: Vertical Lean Direction Arrow.
Source: Fox and Associates

Using elevation views, it can be difficult to interpret the data, especially in linking plan and elevation views to each other. It is challenging to present the data in a way that makes an obvious link between a plan view and the elevations. Some traditional uses of plan and elevation view combinations do not require ready comparison between elevation views. With this data, however, it is very useful to be able to compare elevation views with one another in a meaningful way, to better comprehend the data presented and how it portrays the condition of the structure under survey. To enable this, the elevation views must be arranged suitably, with clearly identifiable links to the plan view. Employing the use of colour for this purpose, assigning unique colours to individual walls of the building, and likewise colouring the elevation views has proved effective in clarifying the connection between plan and elevation views. Please see Figure 4 and Figure 5 below for an example of this.

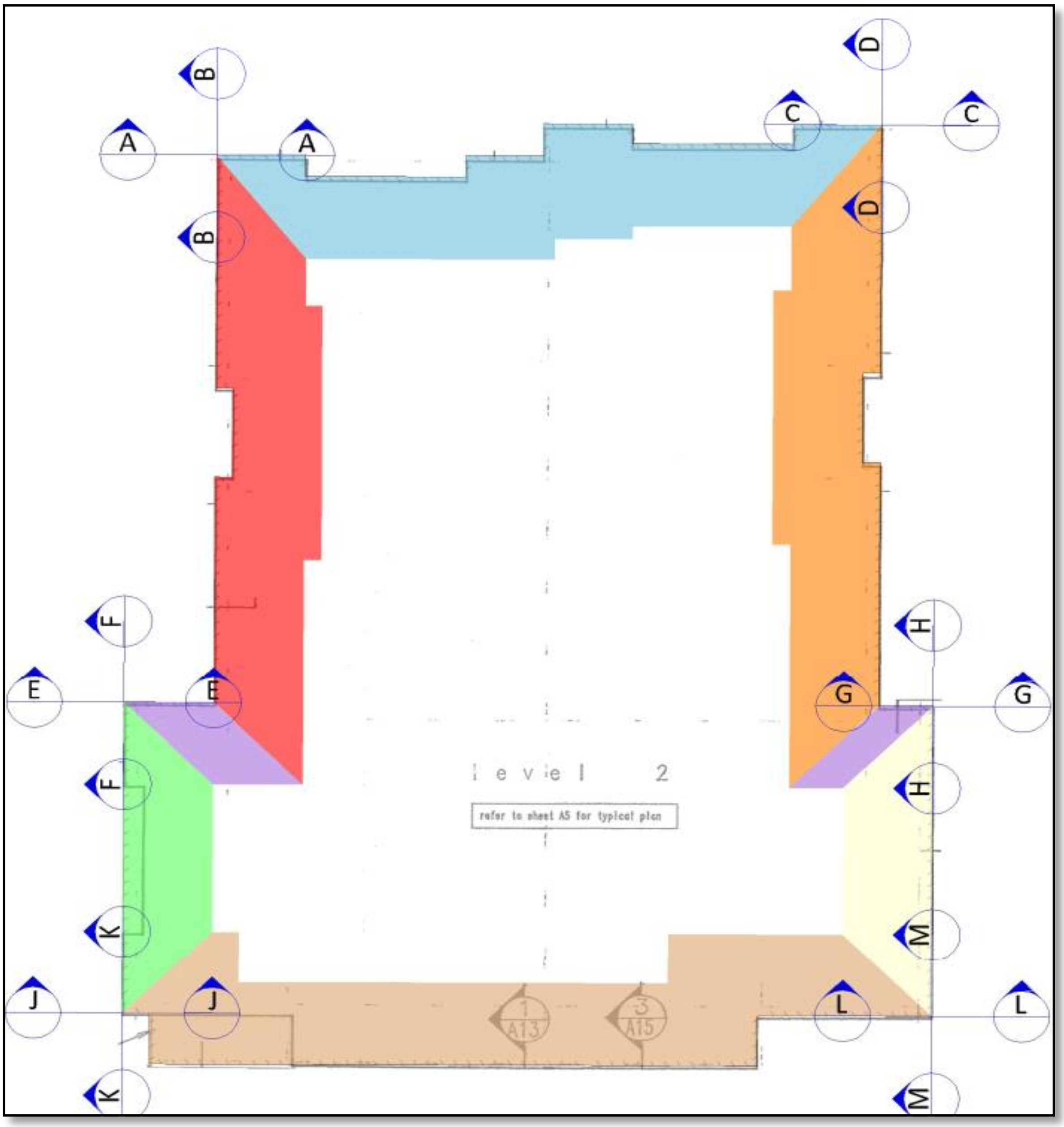

Figure 4: Plan View - Plan and Elevations. Source: Fox and Associates File 3305P

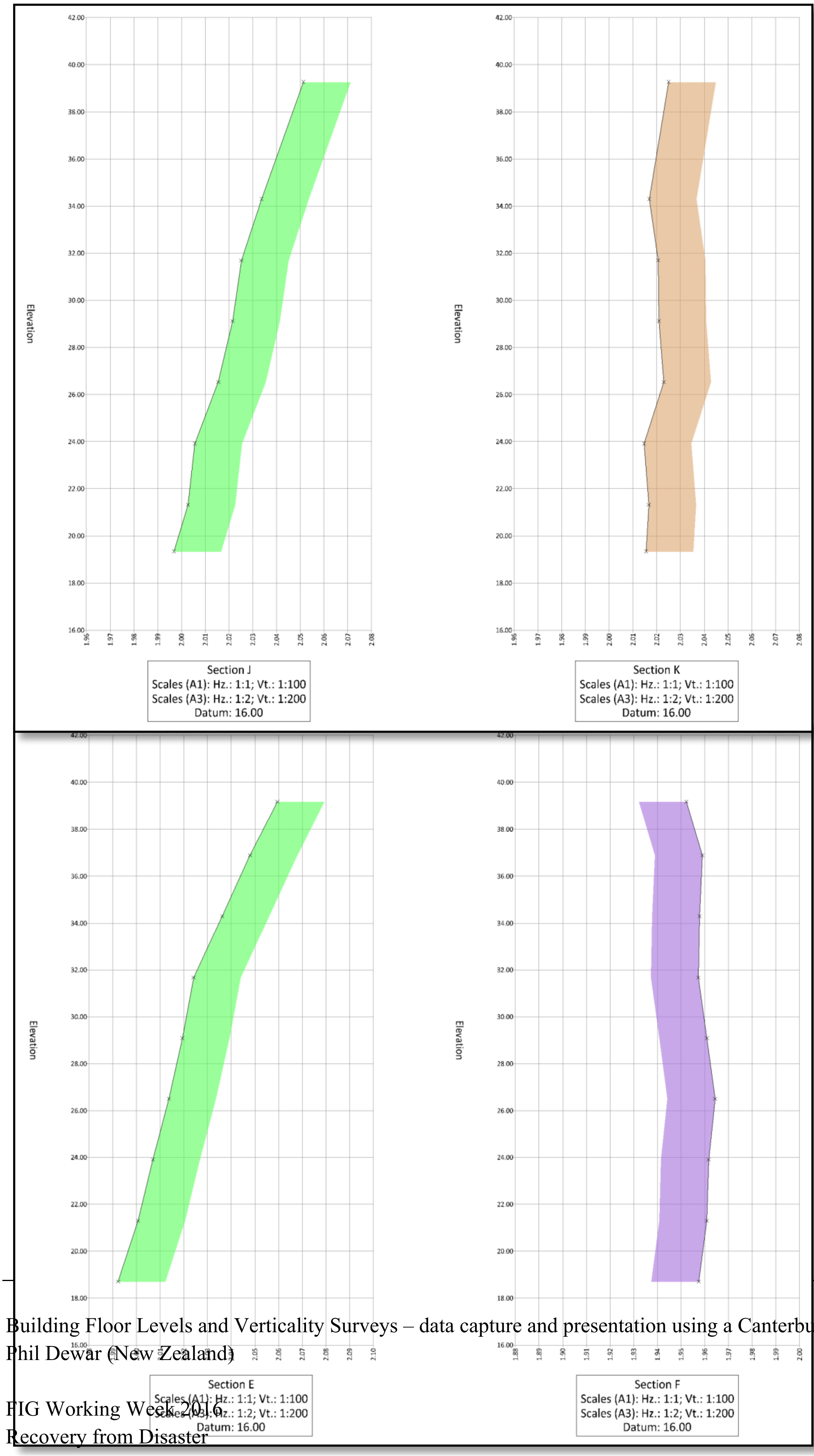

Figure 5: Elevation Views – Plan and Elevations. Source: Fox and Associates File 3305P

With point cloud data, the deliverables can be richer and more complex, because of the greater quantity of observed data captured. This does not, however, simplify the data presentation process. As with any point cloud survey, it is very important to understand at the outset what the final deliverable will be, to ensure that the correct data (density and accuracy) is captured.

3.3.2 Floor Levels Data Presentation

The primary purpose of the floor levels data is to provide a picture of the current state of the floor of a building or structure. Having measured and reduced the discrete floor levels observed, these are plotted onto a floor plan of the building.

The bare minimum required presentation is a floor plan showing elevation labels at each measured location. It can, however, be difficult to understand a plan scattered with numbers and no additional cues to guide interpretation – even to the experienced professional, let alone the layperson. Some such cues to assist with this may include the following:

- Contours lines of equal elevation or relative to an average plane.
- If data has been captured in terms of an external datum, applying a false-origin elevation to set the lowest, mean or highest measured elevation to a round figure – such as 0.000m or 10.000m – which may allow for more efficient data interpretation.
- Applying elevation colour shading, such as a changing colour hue or two-colour blend, to the elevation data assists in making the varying floor levels very obvious. A suitable colour scheme may range from darkest blue for the lowest elevations, through light blue to transparent at the average floor level, and then through light red to dark red

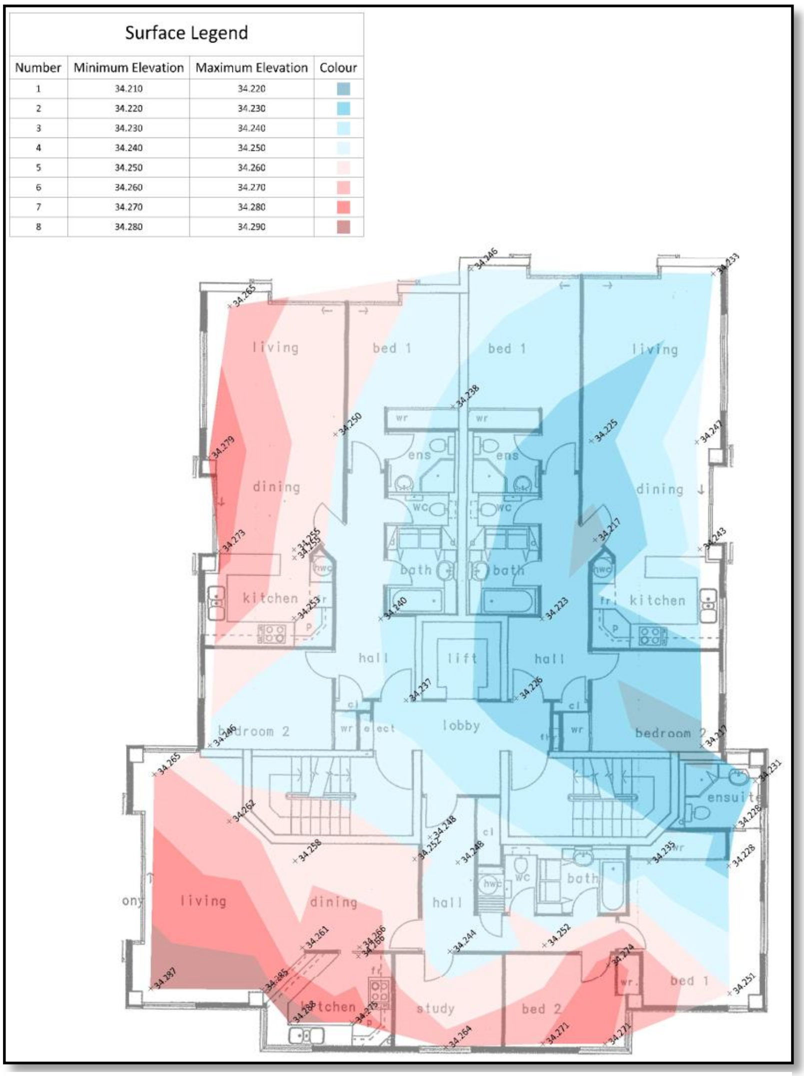

Figure 6: Floor Levels Colour Scheme. Source: Fox and Associates File 3305P

for the greatest elevations. (see Figure 6)

− Slope analysis on the measured floor level data, to display those areas of the floor that may have a greater-than-specified tolerance of floor slope, again displayed with colour variation.
− The inclusion of a colour shade legend assists the casual observer in interpreting the extent of floor level variation seen.

Applying additional visual cues dramatically improves the presentation and ease with which the data can be interpreted. Regardless of the additional plan presentation tools used, it remains important to retain the measured reduced levels on the plan, thus ensuring the full data set, as captured, is still available for any necessary analyses.

3.4 The Role of the Surveyor

The roles that Surveyors do, and do not, play in the building assessment process should also be recognized. A professionally competent Surveyor has the training, experience and qualifications to take the appropriate measurements and assert the as-observed spatial extents of the structure at the time of survey. The Surveyor understands the degree of accuracy with which that data has been collected and methods to manage errors during data capture and reduction.

It is also the role of the Surveyor to ensure that the client and end-users clearly understand the data which they are presenting. This is likely to extend to reporting on patterns or trends in data delivered data and how significant these are relative to resultant data accuracies.

Broadly speaking, the Surveyor’s role can be summarized as:

- Accurate and reliable measurement of the required structures,
- Confidence in the level of accuracies expected and delivered, and
- Delivery of clear and unambiguous data for future use.

There may also be a temptation to speculate on potential causes for any damage that the data highlights, or for drawing conclusions that go beyond the realm of what has been measured. It is difficult to categorically state, for example, that floors have behaved in a particular way due to earthquake damage, without also having measured data from before the earthquake. Similarly, while a building may or may not appear to have suffered particular damage, the Surveyor is not the professional responsible for judging the structural integrity of that building.

The Surveyor is typically one member of a team of professionals that have involvement in the assessment of a building or structure and it is invariably the role of other professionals, such as Structural Engineers, Loss Adjusters or Quantity Surveyors, to draw the final conclusions on the amount of damage, the causes of damage and what remedial works may follow.

4. CONCLUSION

The Canterbury earthquakes have given local Surveyors a whole new sphere of work than had ever been envisaged before. They have encountered many challenges that required untried techniques and have consequently resulted in significant learnings. Some such challenges have been in measuring the condition of buildings and structures, for floor level and vertical condition variation.

Surveyor's responsibilities lie in both accurately capturing the positional data and clearly presenting that data in a manner that all foreseeable end-users will understand. At times this may require some additional effort to achieve, and may even result in changes to on-site measurement workflow, to ensure that the data can be most usefully presented.

REFERENCES

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http://info.geonet.org.nz/display/quake/M+6.3%2C+Christchurch%2C+22+February+2011 accessed 14/02/2016.
The majority of this paper has been drawn from the experiences of the Author and of Fox and Associates. These come from a mixture of projects carried out by Fox and Associates, and discussions with clients, consultants and others regarding industry best-practice.

The author has previously presented on similar topics at the Trimble Dimensions Conference 2012, and the New Zealand Institute of Surveyors Conference 2013. While no content directly overlaps, it is acknowledged that some portions of this paper may have previously been covered in the above presentations. Neither of the above presentations supported a published paper.

Earthquake Details (Sections 2.1, 2.2): Details of the quakes sourced from www.geonet.org.nz

Some examples and figures have been given based on some specific cases and projects that the author has been involved with. It is the preference of the relevant clients that the identity of their projects be withheld.

BIOGRAPHICAL NOTES

Phil Dewar is a Registered Professional Surveyor with Fox and Associates in Christchurch, New Zealand. He graduated from Otago University in 2004 and has been working in private practise in Christchurch since 2005. He has developed expertise in the areas of spatial measurement and cadastral surveying. Interests outside his work include his family and occasional social soccer.

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