Cyclic Testing Methodology for Temporary Propping of Tilt-up Panels for Wind Loading Effects

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Abstract:

Precast and tilt-up construction methods require temporary props to provide the necessary structural support to panels during the erection phase. The temporary prop system must be capable of supporting the panel against all loads until the panel has been permanently secured. Traditionally, the design for wind loading on temporary props has been considered through an equivalent static load, including the serviceability condition that is based on the ultimate wind load divided by a factor of safety. Typical anchorage of the temporary prop includes cast-in ferrules when fixing to the precast panel and post-installed brace fixture inserts in the floor structure. The development of a dynamic test procedure for prequalification of anchor systems for this application requires an accurate review of wind loads expected throughout the intended service life of the temporary prop.

This paper considers modelling of the fluctuating propping forces associated with the design wind condition for temporary structures for the purposes of establishing a test loading regime for the prop connections to validate their sufficiency. A spectral based model is considered both directly and indirectly (through time domain simulation via a random phase spectral modelling approach and a rainflow cycle counting technique), to develop such a test loading regime.

Keywords: Tilt-up panels, wind loading, cycle counts, spectral excitation models

1. INTRODUCTION

Tilt-up and precast panel construction has become increasingly more popular worldwide for economical structural solutions to low-rise office, residential and general commercial building forms. This style of construction essentially developed following the introduction of the mobile crane in the mid 1940's and was initially in demand for warehouse construction (Crompton, 1992). Despite the popularity of tilt-up construction over the several decades of its widespread use world-wide, the design for the temporary condition of propping tilt-up or precast panels has been fraught by controversy amongst the engineering profession both in Australia and overseas as to what design load conditions should be considered given the "temporary" nature of this propping. The development of a dynamic test procedure for prequalification of anchor systems associated with this "temporary" propping condition for tilt-up construction forms part of this controversy.

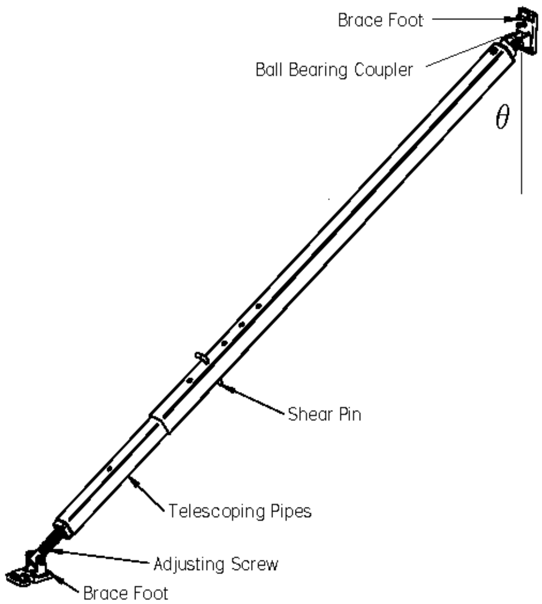
In Australia, The National Code of Practice for Precast, Tilt-up and Concrete Elements in Building Construction, published by the Australian Safety and Compensation Council in 2008, governs all design aspects of tilt-up panel construction practice. Reference is made to the requirements of certification by a qualified structural engineer of the design of the bracing whereby the design structural engineer attests to: "*I certify that the temporary bracing layout as detailed in the drawings listed below has been checked for wind loading and complies with AS 3850 Tilt-up concrete and precast concrete elements for use in buildings and AS/NZS 1170.2 Structural Design Actions – Wind actions*".

The draft version of AS 3850 part 2, issued for comment 12th March – 14th April, 2013, states: *"Wind loads on elements that are temporarily braced shall be determined from AS/NZS 1170.2 using annual probabilities of exceedance based on tables Table F1 and F2 of AS 1170.0 and wind forces shall be divided by 1.5 when comparing them with the working load limit of temporary braces. Where the 'drop zone' of the element is within the building site a minimum importance level 2 in accordance with AS/NZS 1170.2 shall be used. Where the drop zone of the element is beyond the building site boundary, the importance level (see Table F1 of AS/NZS 1170.0) of the adjacent property shall be considered."* For Importance level 2 "sites", this requirement results in a 100 Year Return Period (YRP) and 25 YRP wind for ultimate and serviceability conditions, respectively.

The application of 100 YRP wind conditions to the design of fixing elements that may be in temporary service for just a few days has been the source of some controversy amongst the engineering profession. That these design conditions could reasonably apply to the prop or brace element that tends to be re-used a large number of times on subsequent panel propping applications tends not to be the subject of this same controversy.

Wang and Pham (2012) discuss various interpretation options for maintaining the rationale behind the Building Code of Australia (BCA, 2010) for the design wind speed for temporary structures (defined therein as *structures with a total period of use to perform its intended purpose less than one year*). Wang and Pham show that design wind speeds could be reduced up to 50% of those recommended in the BCA depending on the Importance Level and reduced period of use. This can translate to a corresponding reduction in wind loads of up to 75%, i.e. wind loads reduced down to 25% for one week of continuous use compared to one year of such use, whilst maintaining the probabilities of exceedance of wind loads for such temporary structures to be the same as for the annual probabilities of exceedance required by the BCA.

Notwithstanding possible future changes in the rationale of the BCA in its definition of temporary structures and their one-time use to include time periods corresponding to 6 months, 3 months, 1 month, or even as low as 1 week, we will "run with" the current definition of one year as the design working life both for props/bracing as well as fixtures, (see Figs. 1(a) and 1(b) for schematics of a typical prop and typical configuration of a tilt-up or precast panel).



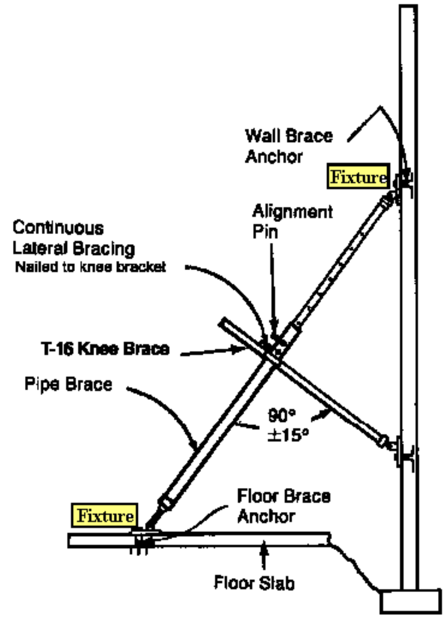


Figure 1(a): Typical prop used on tilt-up panels Figure 1(b): Typical panel propping and bracing
(*Tilt-up Precast Construction Handbook, March 2012*)

2. WIND LOADING ON PANELS

Holmes (2007) provides a comprehensive description of wind, its characteristics and loading effects on structures, including promotion of their dynamic response. Much of this treatment and understanding appears in the codes of practice for wind loading on structures of several countries, including Australia. Here, a wind loading model for the along-wind response of a rectangular tilt-up panel will be developed using a spectral modelling approach described in Holmes (2007) and originally developed by Davenport (1961), and extended here by the authors.

2.1 Modelling Response of Tilt-up Panels to Along-wind Turbulent Wind Loading

Consider a propped, isolated, tilt-up panel (as in Fig 1(b)) of width B and height H, and exposed area $A_p = B \times H$, responding dynamically to wind with a one-hour mean speed of $\overline{U}$ and along-wind fluctuations of $u(t)$, with a displacement amplitude $\eta(t)$ at the centroid of the panel. C_d is the drag (or pressure) coefficient is and p_d is the dynamic pressure. If the fluctuating wind force at the panel centroid is taken as $F_U(t)$, air density is ρ and relative velocity $U_r(t)$ of the moving panel against the wind at the centroid is responsible for this forcing, then, for panel velocity given by $\dot{\eta}(t)$, we have:

$$F_U(t) = p_d \; A_p \; C_d = \left[\frac{1}{2}\rho U_r(t)^2\right] \; A_p \; C_d \tag{1}$$

$$\begin{aligned}
F_U(t) &= \frac{1}{2}\rho A_p \; C_d \left(\{\overline{U} + u(t)\} - \dot{\eta}\right)^2 \\
&= \frac{1}{2}\rho A_p \; C_d \left(\{\overline{U} + u(t)\}^2 + \dot{\eta}^2 - 2\dot{\eta}\{\overline{U} + u(t)\}\right) \\
&\approx \frac{1}{2}\rho A_p \; C_d \left(\overline{U}^2 + u(t)^2\right) + \frac{1}{2}\rho A_p \; C_d \times 2\overline{U}u(t) - \frac{1}{2}\rho A_p \; C_d \times 2\overline{U}\dot{\eta} \\
&= \frac{1}{2}\rho A_p \; C_d \left(\overline{U}^2 + {u_{RMS}}^2\right) + \rho A_p \; C_d \overline{U}u(t) - \rho A_p \; C_d \overline{U}\dot{\eta} \\
&= \overline{F} \; + \; F_u(t) \; - \rho A_p \; C_d \overline{U}\dot{\eta}
\end{aligned} \tag{2}$$

From Eq. (2) the mean wind force on the panel at the centroid is given by:

$$\overline{F} = \left[\frac{1}{2}\rho\left(\overline{U}^2 + u_{RMS}{}^2\right)\right]A_p C_d = \frac{1}{2}\rho\overline{U}^2\left(1 + I_u{}^2\right) \tag{3}$$

where I_u is the intensity of along-wind turbulence for the site category in which the panel is located. In addition, fluctuating force at the panel centroid, $F_u(t)$, is given by:

$$F_u(t) = \rho\,\overline{U}\;A_p\;C_d\;u(t) \approx 2\overline{F}\,\frac{u(t)}{\overline{U}} \tag{4}$$

from which it can be shown that the coefficient of variation of fluctuating wind force is twice that for fluctuating along-wind wind speed i.e. twice the intensity of along-wind turbulence, $I_{u.}$

Now the dynamic equation of equilibrium for fluctuating displacement response of the panel at the centroid of *η(t)* can be modelled using a Single Degree of Freedom (SDOF) assumption in which c_s is the structural damping co-efficient, *m* is the effective mass of the pivoted panel at the centroid, and *k* the effective horizontal spring stiffness of the props, also at the panel centroid, so that:

$$m\ddot{\eta} + c_s\,\dot{\eta} + k\,\eta = F_U(t) \tag{5}$$

$$m\;\ddot{\eta}\;+\;\left(c_s + c_a\right)\;\dot{\eta}\;+\;k\;\eta\;=\overline{F} + F_u(t) \tag{6}$$

in which $c_a = \rho\,A_p\;C_d\overline{U}$ represents, so-called aerodynamic damping.

The mean displacement at the centroid is given by $\overline{\eta} = \dfrac{\overline{F}_u}{k}$ and the fluctuating component of *η(t)* can be obtained from Eq. (6) by omitting the mean force term.

2.2 Spectral Model of "Dynamically-enhanced" Along-wind Wind Loading on Tilt-up Panels

Alternatively, a spectral modelling procedure can be adopted for treatment of Eq. (6), which allows for the introduction of an aerodynamic admittance function, $\chi_a(f)$, that essentially accounts for the influence of the area or size effect of the panel in reducing the loading from the higher frequency, smaller size eddies/gusts, as they tend not to be able to envelope the whole area (are less correlated) with progressively higher frequencies. Our interest here is centred on the horizontal "spring force" at the panel centroid, given by *k.η(t)*. This force can alternatively be interpreted as a "dynamically enhanced" fluctuating wind load at the panel centroid from which the fluctuating force in the props can then be determined using statics and the basic geometry of the propping arrangement.

The spectral model for the "dynamically enhanced" wind load at the panel centroid is described diagrammatically in Fig. 2. In this model, $S_u(f)$ and $S_F(f)$ are the spectral densities for along-wind turbulence and "dynamically enhanced" wind load at the panel centroid for the site conditions of interest, respectively; ζ, represents the critical damping ratio associated with combined structural and aerodynamic damping; f_o is the natural frequency of the pivoted panel and prop assembly; $T(0) = \rho\,\overline{U}\;A_p\;C_d\,(0)$ whilst $T(f)$ is given by $\rho\,\overline{U}\;A_p\;C_d\,(f)$ which allows for frequency dependence in the drag coefficient, C_d; $\sigma_u{}^2$ and $\sigma_F{}^2$ represent the variances in wind and wind force respectively. $\chi_m(f)$ is the structure magnification function given by:

$$\chi_m(f) = \frac{1}{\sqrt{\left[1 - \left(\dfrac{f}{fo}\right)^2\right]^2 + \left[2\zeta\left(\dfrac{f}{f_o}\right)\right]^2}} \tag{7}$$

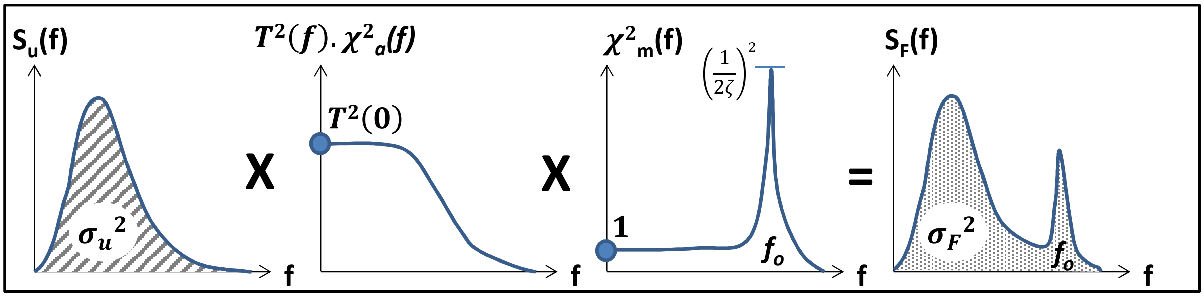


Figure 2: Diagrammatic description of spectral modelling approach to wind load at panel centroid

2.3 Simulation of "Dynamically-enhanced" Along-wind Wind Loading on Tilt-up Panels

A spectral based random phase model can be used to simulate the "dynamically-enhanced" along-wind wind loading on tilt-up panels, $F_W(t)$, based upon the procedure outlined in §2.2 above (Haritos, 2010). Consider a time series for $F_W(t)$ consisting of N points obtained at a regular time step of dt over a time period of duration of T_d (where $T_d = Ndt$), then a Fourier series representation of $F_W(t)$ for $f = n/T_d$, $df = 1/T_d$ and $\phi =$ Random (0 – 2π), becomes:

$$F_W(t) = \sum_{n=1}^{N/2} (a_n \cos\frac{2\pi nt}{T_d} + b_n \sin\frac{2\pi nt}{T_d});\quad a_n = \sqrt{2S_F(f)df}\cos(\phi),\ b_n = \sqrt{2S_F(f)df}\sin(\phi) \qquad (8)$$

In order to "drive" Eq. (8) for the applicable site design wind speed conditions, $T(f) = T(0)$ can be adopted and functional forms for $\chi_a(f)$, and for the along-wind speed spectrum, $S_u(f)$ are required.

An expression proposed by Vickery (1968) can be used for the aerodynamic admittance function,

$$\chi_a(f) = \frac{1}{1+\left(\dfrac{2f\sqrt{A_p}}{\overline{U}}\right)^{4/3}} \qquad (9)$$

For the along-wind wind speed spectrum, $S_u(f)$, there are a number of forms one can choose. Here, Davenport's form is adopted, viz:

$$\frac{f\,S_u(f)}{u_*^{\,2}} = 4.0\frac{n_f^{\,2}}{\left(1+n_f^{\,2}\right)^{4/3}};\qquad n_f = \frac{L_u f}{\overline{U}_{10}} \qquad (10)$$

Equation (8) can be realised using an Inverse Fast Fourier Transform (IFFT) available in most scientific packages, eg Matlab, Labview, etc, and even in spreadsheets such as MS-Excel to produce the "dynamically-enhanced" along-wind loading on the tilt-up panel under consideration for any condition including the ultimate design wind condition, i.e. for the 100 YRP wind. What remains to be determined in the model is the value of $\overline{U}$ from knowledge of V_{des} - the design value of 3-second gust wind-speed, for the site conditions concerned, and a 100 YRP.

2.4 Relationship between Wind Speeds for Different Averaging Periods

Holmes and Allsop (2013) and Holmes and Ginger (2013) discuss some issues that can arise when raw anemometer data based upon different anemometer types are used in design codes without modification to account for variation in their "response times". The so-called "3-second" gust has remained as the "averaging period" for the peak gust value in a one-hour storm period in AS/NZS

1170.2. Whereas earlier AS versions of this code provided relationships (Gust Factor) values for different site conditions that allowed evaluation of $\overline{U}$ from V_{des}, the later versions of this code have instead adopted the modelling approach of Fig. 2 to evaluate C_{dyn} and no longer provide these relationships. C_{dyn} is expressed as:

$$C_{dyn} = \frac{1 + 2I_h \left[g_v{}^2 B_s + \frac{H_s g_R{}^2 S E_t}{\zeta} \right]^{0.5}}{(1 + 2 g_v I_h)} \tag{11}$$

AS/NZS 1170.2 defines all terms in Eq. (11) for the spectral model, and suggests that g_v = 3.7 and C_{dyn} be taken as 1.0 for natural frequencies, f_o, greater than 1 Hz - the expected condition for propped tilt-up or precast panels. (This condition is near equivalent to setting $\chi_m(f)$ =1 in the model of Fig. 2). From Eq. (11), for I_h being turbulence intensity at the top of the panel, we obtain:

$$1 + 2I_h \left[g_v{}^2 B_s + \frac{H_s g_R{}^2 S E_t}{\zeta} \right]^{0.5} = 1 + 2 g_v I_h \tag{12}$$

and, by equating the Mean Wind Force at the centroid of the panel times the Dynamic Gust Factor to the peak 3-second Design Wind Force thereat, we obtain:

$$\frac{1}{2} \rho C_d A_p \overline{U}^2 \left(1 + I_z^2\right) \times \left(1 + 2 g_v I_h\right) = \frac{1}{2} \rho C_d A_p V_{des}{}^2 \tag{13}$$

so that $\frac{V_{des}}{\overline{U}} = \sqrt{\left(1 + I_z^2\right) \times \left(1 + 7.4 \times I_h\right)}$ (14)

which is a form of Gust Factor for peak wind gusts of 3-second duration from mean one-hour wind.

3. APPLICATION TO AN EXAMPLE PANEL

Here, we consider an example application to a typical tilt-up panel of the methodology detailed in §2. This would allow the determination of a simulated “dynamically-enhanced” design along-wind force time-history on the tilt-up panel under consideration in the example. The resultant force trace can then be investigated to interpret the loading applied at the prop fixtures.

A testing machine that can operate in load control to an arbitrary control input (such as the load history acting on a prop fixture obtained via the above simulation), can be directly used to test the performance of a proposed fixture configuration for its “fitness for purpose”. Alternatively, details of the fixture force time history obtained from such a simulation can be investigated to obtain alternative load testing procedures, eg via cycle counting using a rainflow analysis (Ariduru, 2004).

Another simulation approach, is to use a simplified interpretation of the spectral modelling procedure of §2, wherein the “dynamically-enhanced” design along-wind force spectrum is divided into a small number of equal area divisions, (equal amplitude Fourier harmonics) with a random phase (0 - 2π). This much reduced term Fourier series can then be used to produce the simulated “dynamically-enhanced” design along-wind force time-history for the panel (Haritos, 2010). For N Fourier wavelets in the series, the amplitude of each, A_n, simply becomes, $A_n = \sqrt{2/N}\,\sigma_F$, which for N = 8 equates to $\sigma_F/2$. The corresponding frequency of the wavelet is taken to be at the half area position within the area segment associated with the wavelet sequence number, n, under consideration. The frequency for the n^{th} wavelet in the series, f_n, is then obtained from:

$$\int_{f_n}^{\infty} S_F(f)\,df = \frac{2(N-n)+1}{2N} \sigma_F^2 = \frac{2(N-n)+1}{2N} \int_0^{\infty} S_F(f)\,df \tag{15}$$

The maximum panel along-wind wind force in this model, F_{max}, occurs when all wavelets are in phase, $F_{\max} = \sqrt{2N}\sigma_F$, which for N = 8 equates to 4 times the RMS value. This value is close to but greater than the value of 3.7 for g_v and the Dynamic Gust Factor of $1 + 2g_v I_h$ suggesting that using N at least equal to 8 would be necessary for modelling the panel along-wind force time history to obtain a reasonably good approximation to simulated along-wind wind force.

A closed form solution to Eq. (15) for f_n is only realisable for $\chi_a(f) \approx 1$ which condition would imply that panel area A_p in Eq. (9) is small, say less than 1 m^2 at f = 1 Hz, which is not a practical condition for a tilt-up or precast panel. Consequently a simple numerical technique that investigates for the appropriate proportion of the entire area under the along-wind wind force spectrum associated with wavelet frequency f_n can instead be exercised to determine this wavelet frequency.

3.1 Properties of Example Panel

Figure 3 depicts some of the basic features of the example tilt-up panel being considered here to illustrate the alternative approaches for simulating the prop forces acting on the base fixtures from the 1-hour along-wind Design Wind storm. In addition, a dynamic modal analysis suggests the first mode frequency to be approximately 18 Hz, with a mode shape as depicted in Fig. 3 for this panel.

The panel is 3m wide and 4m tall, 0.12m thick, approximately 4 tonne in mass, and restrained by two props inclined at 45 degrees. It is located in Melbourne suburban conditions (Category 3) where V_{100} = 41 m/s from Table 3.1 of AS/NZS1170.4. Considering wind from any direction M_d = 1, no shielding, M_s = 1, or topographic effects, M_t = 1, then for z < 10, Table 4.1(A) yields a terrain height multiplier of 0.83, so that the design ultimate 3-sec gust speed, V_{des}, becomes 0.83 x 41 = 34 m/s. Table 6.1 notes I_u = 0.271, for I_z and I_h, so that from Eq. (14), $\overline{U} = 0.557 \times V_{des} = 19.0$ m/s.

Table D2(A) of AS/NZS1170.2 provides equations that allow the drag coefficient C_d, equivalent to the net pressure coefficient $C_{p,n}$ for walls, to be determined as 1.28 from the geometry of this panel.

3.2 Simulation of Design Wind Forces on Panel

The design along-wind panel wind force trace, $F_W(t)$, was simulated for panel conditions as per §3.1 using an IFFT based MS-Excel program written for this purpose producing 4096 data points at 1 second intervals. One hour's worth of data (3600 points) was extracted from this record and a moving 3-second averaging filter applied to the trace to produce a 3-sec averaged version of $F_W(t)$ for the purposes of comparison. In addition, 8, then 16 wavelet formulations of the panel wind force trace, using the method outlined in §3 were also produced, again for comparison purposes.

Figure 4 depicts the 3-sec averaged version of $F_W(t)$ superimposed on the "raw" version for this

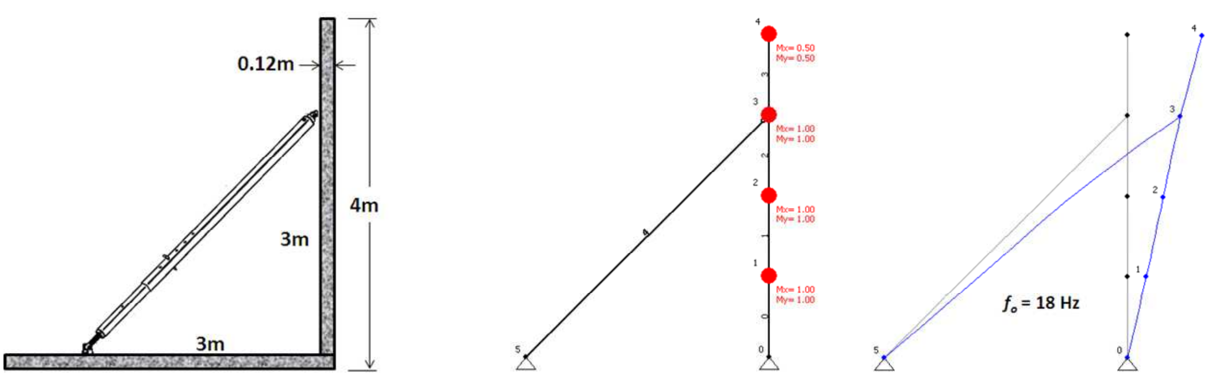


Figure 3: Example tilt-up panel configuration and modal analysis model for first mode

panel wind force record over the full one-hour of simulation. The peak 3-sec Gust Load in a one-hour design wind storm would be given by $0.5\rho\ C_d\ A_p\ V^2_{des}$ = 10.7 kN. The observed peak in the “raw” version of the trace in Fig. 4 is 10.2 kN and the corresponding peak for the 3-sec filtered version of this trace is 9.6 kN, suggesting that the raw version better describes $F_W(t)$ than the filtered version for this particular simulated trace.

Figures 5 and 6 present an 8 and 16 wavelet simulation of the panel design wind force trace, respectively for a one hour period reproduced at 1 second intervals. The peak value of wind force is 9.9 and 10.3 kN in Figs. 5 and 6 respectively which again agrees quite well with the peak 3-sec Gust Load on the panel for design conditions. The 16 wavelet simulation is understandably more “detailed” in its reproduction of wind force fluctuations than the 8 wavelet simulation version.

Figure 7 compares the Cumulative Probability Densities (CPDs) and the Exceedance Probability Density (EPD) curves for the three simulated traces via: IFFT and 8 and 16, equal amplitude Fourier wavelets, for the one hour panel design wind force. Whilst there appears to be a small deviation at the very extreme ends of the tails in these probability distributions, they are otherwise in very close agreement, suggesting that any of these traces could be chosen to be statistically representative of the panel design wind force condition in a one-hour storm.

Hence either the IFFT or the equal amplitude wavelet method, with as few as 8 Fourier terms, all with random phases (0 - 2π) can be used to simulate panel wind forces for the design 100 YRP condition. Testing of fixtures using the prop force trace for this design condition (a scale version of the panel force, $0.67F_W(t)/\sin(\theta)/N_{props}$) could be offered as a prequalification test for such fixtures.

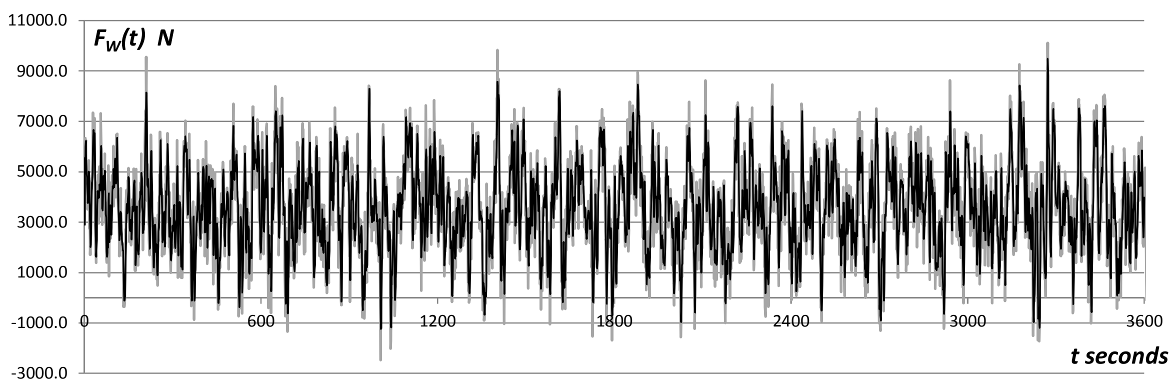


Figure 4: Filtered (3-sec moving average) and raw versions of IFFT simulated one-hour $F_W(t)$

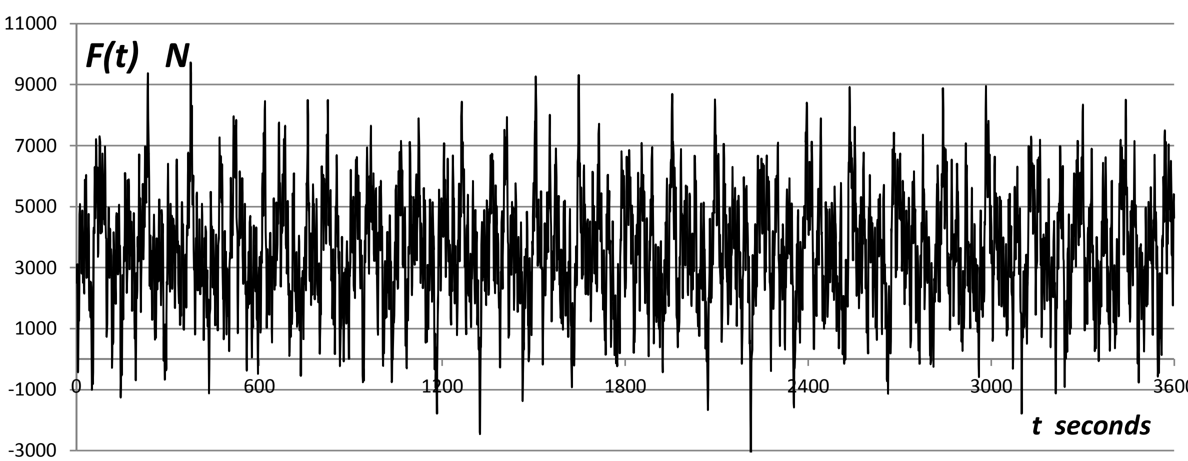


Figure 5: 8 equal amplitude wavelet version of simulated example panel design wind force $F(t)$

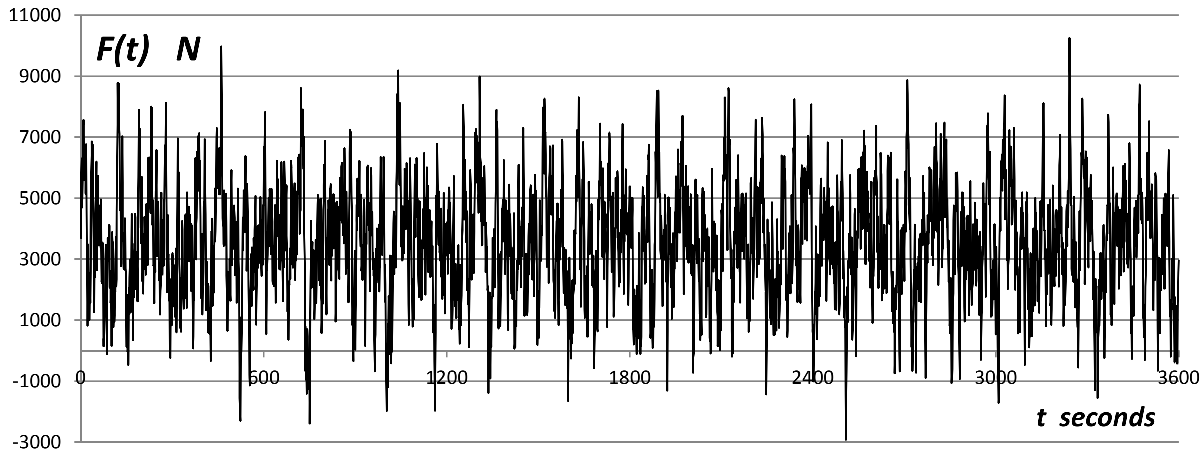


Figure 6: 16 equal amplitude wavelet version of simulated example panel design wind force *F (t)*

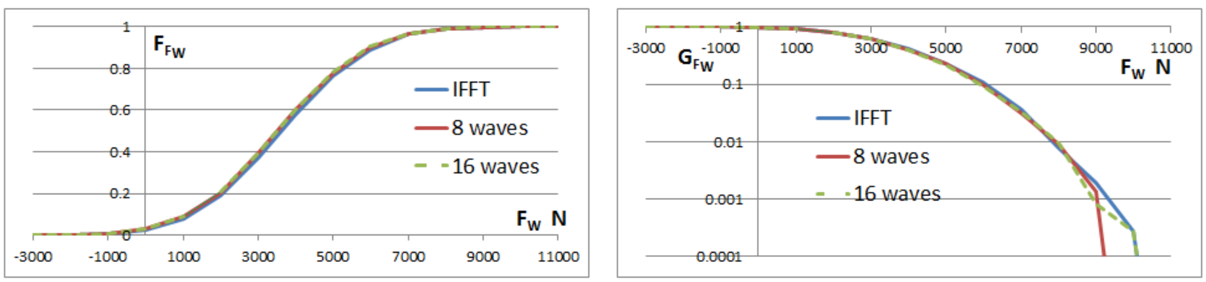


Figure 7: Cumulative and exceedance probability density curves for simulated wind force traces

3.3 A Dynamic Simplified Test Procedure for Prequalification of Anchor Systems

Recently, a simplified dynamic test procedure for the prequalification of anchor systems for props in tilt-up or precast construction has been proposed in DR AS 3850.1 (2013). This procedure is based upon using a peak cyclic load of 1.5 times the Working Load Limit (WLL) of the prop – the WLL is taken as 40% of the prop's ultimate load, viz (ultimate load)/2.5, leading to a peak load of 60% ultimate. In this simplified test procedure, a test rig is set up with loading applied cyclically in tension to the anchor system from 0 to 60% of ultimate prop force for 1000 cycles at 1 to 2 Hz. The question arises as to how does this testing regime relate to wind loading conditions, especially in terms of conditions for ultimate wind loading? An attempt to answer this question for this Simplified Test Procedure (STP) is made here by performing cycle counting of the simulated 100 YRP wind loading traces of our example panel.

3.4 Cycle Counting of Design Wind Forces on Propped Panels

Figure 8 depicts details of the Range-Mean cycle counts for the simulated one-hour 100 YRP design wind load traces for the example panel using program StoFlo, (StoFlo, 2013), obtained from both the IFFT based method and the 8-cycle equal amplitude random-phase Fourier method.

Block cycle testing using the Range-mean counts in Fig. 8 would constitute an alternative testing procedure that can be used instead of the original force time history trace to investigate performance of prop-fixture assemblies under ultimate design wind loading conditions.

Table 1 provides a summary of the results from the cycle count investigations and relates these to the mean (30% of ultimate = 3.21 kN) – which is also the Amplitude, and the peak load of 6.42 kN (or 60% of ultimate) – which is also the range of the simplified dynamic testing procedure of §3.3.

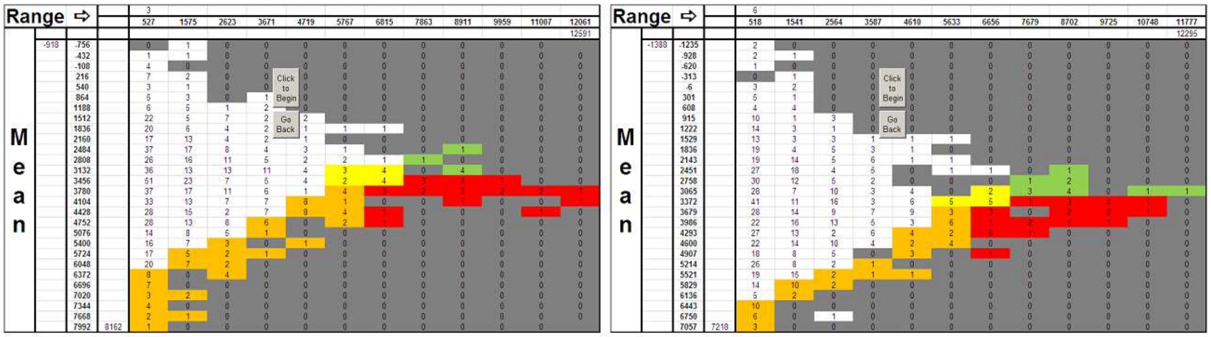


Figure 8: Cycle counts of one-hour simulated design wind traces (a) IFFT (b) 8-wavelet methods

Table 1: Percentage cycle counts with peak exceeding STP peak of 60% ultimate

Percentage Cycles	Mean ≈ STP Amp ≈ STP	Mean > STP Amp < STP	Mean < STP Amp > STP	Mean > STP Amp > STP	Total with Peak ≥ STP
IFFT trace	1.4%	9.6%	0.7%	2.9%	14.6%
8-wavelet trace	1.4%	7.4%	1.5%	3.4%	13.7%

StoFlo obtained 905 cycle counts from the one-hour IFFT simulated ultimate 100 YRP load trace whereas 853 such counts were obtained from the equal amplitude 8-wavelet random phase version. This number of cycles compares reasonably well with the 1000 cycles of the STP. Table 1 suggests that approximately 1 in 7 cycles in the one-hour ultimate 100 YRP wind storm exceed the peak value of 60% ultimate load of the STP, so that 6 in 7 cycles have a Mean-Amp combination that produces less than the peak of the STP.

It would therefore appear that the STP would not be unreasonable for prequalification testing of anchor systems in propping applications of panels in tilt-up or precast construction.

4. CONCLUDING REMARKS

This paper has detailed simulation techniques, based upon spectral modelling, that can be used to model the wind loading of tilt-up or precast panels. The models proposed are an IFFT random phase procedure and an equal amplitude Fourier wavelet approach that can use as few as 8 wavelets to reproduce the time-history of wind loading for the site conditions and geometry of the panel being considered for the wind loading of interest.

When the wind loading condition corresponds to ultimate (100 YRP wind), the method can be used to provide a time history over one-hour at 1-sec intervals of the panel loading. This loading can then be translated to a prop force time-history for the purposes of investigating and comparing the performance of various prop fixtures in terms of a prequalification test for such fixtures. Cycle-counting using rainflow analysis can be exercised on the modelled wind force time traces to obtain a block cycle testing regime as an alternative to direct signal testing. The cycle-counting method however, loses information on frequency content as the trace is reduced to a number of cycles with associated Mean-Range characteristics.

A much simplified method, labelled here as the dynamic Simplified Testing Procedure, or STP, uses 1000 cycles at 1-2 Hz ranging from 0 to 60% of ultimate prop force on the prop-fixture test assembly as the prequalification test of anchor systems in panel propping applications. This procedure can be related to the ultimate one-hour wind loading condition following cycle counting via a rainflow investigation of this simulated ultimate wind loading condition. It is found from the sample panel investigation performed in this paper that 1 in 7 cycle counts at ultimate exceed the peak load associated with the STP, which infers that 6 out of 7 cycles are below this peak.

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