

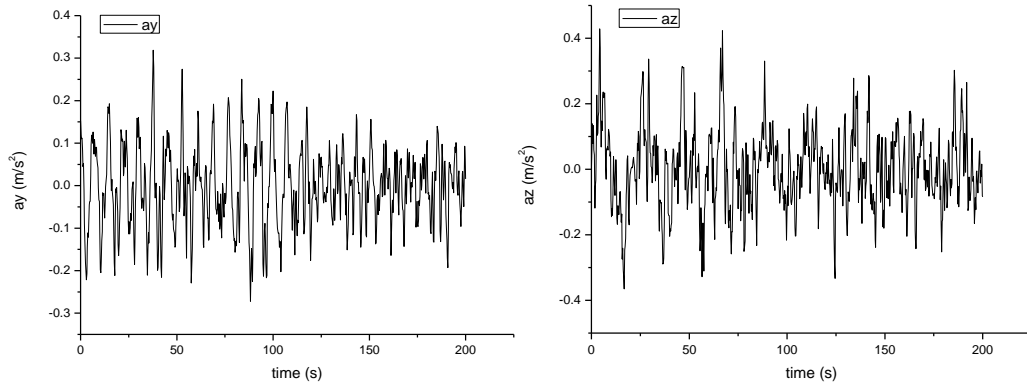
Where C'_L, C'_M are the derivatives of lift coefficients and pitching moment coefficients

considering attack angle; K is the reduced frequency; n_x, n_θ are transforming factors for vertical motion and torsional motion respectively.

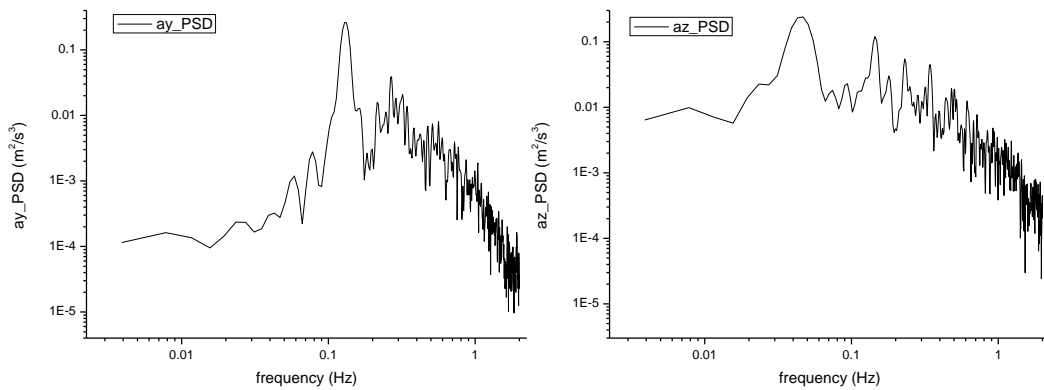
3.5 Buffeting Response of Catwalk

By conducting the time domain analysis, we can get the buffeting responses of the catwalk. The lateral and vertical acceleration response of the middle node in the mid span is shown in Fig.10. Their power spectra density is shown in Fig.11.

From Fig xx, the response frequency is close to the 1st lateral and vertical bending modal frequency, thus indicating the accuracy of the time domain buffeting analysis.



(a) Vertical acceleration time history (b) lateral acceleration time history
Fig.10 Time history of acceleration response of the middle node in the mid span



(a) Vertical acceleration PSD (b) lateral acceleration PSD
Fig.11 PSD of acceleration response of the middle node in the mid span

4. Comfort Evaluation of Catwalk under Construction

4.1 Comfort Evaluation Based On ISO 2631 standard

According to the buffeting analysis results in the previous section, the catwalk vibrates in a frequency range less than 0.5 Hz. So vibration of the catwalk is evaluated based on the part of ISO 2631-1-1997 for evaluating the incidence of motion of sickness (apply to motion frequencies below 0.5 Hz) (Standardization 1997). Referring to the standard, the weighted root mean square (RMS) of the acceleration shall be determined first. Although the vibration shall be assessed only with respect to the overall weighted acceleration in the z-axis, using this method to evaluate the vibration of the catwalk in the y-axis can also indicate the comfort level qualitatively to some extent. The weighted RMS acceleration value is given by,

$$A_{rms} = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}}$$

Where a_w is the frequency weighted acceleration, T is the lasting time of vibration.

This standard recommends a single frequency weighting W_f for the evaluation of the effects of vibration on the incidence of motion sickness. In this study, it is assumed the time fluctuating wind acting on the catwalk is the same, so the vibration time is neglected in the evaluation. When the weighted RMS acceleration is calculated, the comfort level can be determined referring to Table 3.

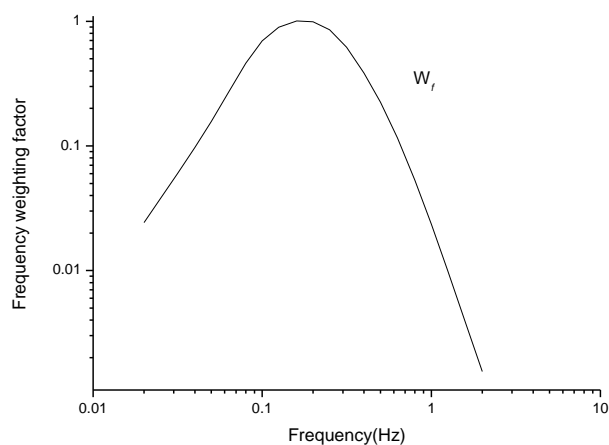


Fig.12 Frequency weighting curves for principal weighting

Table 3 Reactions to various of magnitudes of overall vibration

Frequency weighted RMS acceleration $a_w(m \cdot s^{-2})$	Subjective Response
$a_w < 0.315$	Not uncomfortable
$0.315 \leq a_w < 0.63$	A little uncomfortable

$0.5 < a_w < 1$	Fairly uncomfortable
$0.8 < a_w < 1.6$	Uncomfortable
$1.25 < a_w < 2.5$	Very uncomfortable
$a_w > 2$	Extremely uncomfortable

4.2 Comfort Evaluation Based on Annoyance Rate Model

Compared to ISO 2631-1-1997, this method based on annoyance rate model can further estimate quantitatively the number of constructors on site who feel discomfort due to vibration. A fuzzily random evaluation model on the basis of annoyance rate for human body's subjective response to vibration, with relevant fuzzy membership function and probability distribution given is presented. When assessing the vibration comfort, many different psychological, psychophysical and physical factors, such as individual susceptibility, body characteristics and posture together with the frequency, direction, magnitude and duration of vibration are relevant in development of unwanted effects. (Tang, Zhang et al. 2014) The annoyance threshold acceleration determined by the two valued logic method cannot describe the ambiguity and randomness existing in human response to vibration environments, which results in many uncertainties in the vibration comfort based reliability analysis. All these uncertainties were analyzed from a view point of psychophysics. The membership function and corresponding conditional probability distribution were determined based on the format of field survey table and laboratory findings.

A fuzzy stochastic model for human response to vibrations was presented. SONG, et al, combined the fuzzy logic method, the probability theory and the experimental statistics, to advance a new evaluation index, i.e., annoyance rate method.

Annoyance rate is the rate of unacceptable response under certain vibration intensity. The vibration sensitivity is different according to different range of frequency. The root mean square (vibration intensity) of weighted frequency is adopted internationally as the foundation for evaluating the vibration comfort. The vertical general frequency weighted function can be expressed as follows:

$$W_{ff} = \begin{cases} 0.5f^{-5}, & 0 \leq f \leq 4 \\ 1, & 4 \leq f \leq 8 \\ 8f^{-1}, & 8 \leq f \leq 80 \end{cases}$$

The vibration intensity a_w is given by,

$$a_w = W_{ff} a_{rms}$$

where a_{rms} is the RMS acceleration value. Annoyance rate indicates the ratio of people who cannot accept the external stimulus to the total statistical people. It can be used to

determine the annoyance threshold for vibration comfort. Annoyance threshold means the limit of acceleration on the premise of ensuring acceptable comfort. Under discrete distribution, the annoyance rate can be expressed as,

$$A(a_{wi}) = \frac{\sum_{j=1}^m v_j n_{ij}}{\sum_{j=1}^m n_{ij}} = \sum_{j=1}^m v_j p(i, j)$$

Where $A(a_{wi})$ is the annoyance rate of the i^{th} vibration intensity a_{wi} ; n_{ij} is the number of subjective response of the j^{th} type of the i^{th} vibration intensity; v_j is the membership value of the j^{th} type of unacceptable range, and $v_j = (j-1)/(m-1)$; m is the class number of the subjective response, if the class of “no vibration feeling”, “a little vibration feeling”, “medium vibration feeling”, “strong vibration feeling”, “Extremely uncomfortable” are adopted to describe the subjective response of occupant, then $m=5$; $p(i, j)$ represents the difference of the subjective feeling degree of the occupant, and

$$p(i, j) = \frac{n_{ij}}{\sum_{j=1}^m n_{ij}}$$

Considering the continuous distribution, calculation formula of annoyance rate is represented as

$$A(a_{wi}) = \int_{u_{min}}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_{ln}u} \exp\left(\frac{-(\ln(u/a_w) + 0.5\sigma_{ln}^2)^2}{2\sigma_{ln}^2}\right) v(u) du,$$

Where a_w is the frequency weighted vibration intensity; $\sigma_{ln} = \sqrt{\ln(1+\delta^2)}$, δ is the vibration coefficients, and change from 0.1 to 0.5, based on trial research; $v(u)$ is the fuzzy membership function of vibration intensity, is shown as follows:

$$\begin{cases} v(u) = 0, & u < u_{min} \\ v(u) = a \ln(u) + b, & u_{min} < u < u_{max} \\ v(u) = 1, & u > u_{max} \end{cases}$$

Where u_{min} is the top limit of “no feeling” to vibration of the occupant; u_{max} is the bottom limit of “Extremely uncomfortable” to vibration of human being.

The coefficients of a, b can be obtained from the following equation:

$$\begin{cases} a \ln(u_{min}) + b = 0, \\ a \ln(u_{max}) + b = 1. \end{cases}$$

4.3 Parameter Study

As a temporary structure, old materials such as the gantry ropes from finished projects may be used to assemble the catwalk for the sake of economy. So there are many options for the catwalk rope sizes. However, the change in rope size will result the change of dynamic properties for catwalk, thus affecting the comfort level during construction. Cross bridge, which links two sides of the catwalk and increases the torsional stiffness of catwalk, is also an important part in the catwalk structure. The interval of cross bridges along the span (i.e. the number of the cross bridges) depends on the demand of engineering practice. A narrow cross bridge interval would waste materials and increasing the construction cost, even though the safety of the catwalk is ensured adequately. However, wider cross bridge interval may cause smaller stiffness, affecting structural safety and decreasing comfort level due to vibration.

In that case, a set of rope size and cross bridge intervals listed in Table 4 are chosen to find out their influence on the vibration comfort. With each parameter changes, buffeting analysis and comfort evaluation using two methods would be repeated. According to engineering practice, old materials are seldom used on the catwalk rope. The influence of catwalk rope size is neglected.

As previous stated, different cases were calculated and comfort level is listed in Table 4. From Table.4, we can find that these two methods of evaluating comfort yield consistent results. By comparing the results, the following conclusions can be summarized:

- 1) The comfort evaluation method based on ISO 2631-1-1997 reaches the consistent results with the annoyance rate method. The wind-induced vibration of the catwalk would cause the constructors feel uncomfortable, while the least annoyance rate of 5.58% in the z-axis.
- 2) The method based on ISO 2631-1-1997 can only evaluate the vibration comfort qualitatively, while the annoyance rate method can give a quantitative result.
- 3) Enlarging the gantry rope size and narrowing the cross bridge interval would decrease the frequency weighted RMS acceleration and annoyance rate in both y and z-axis.
- 4) Enlarging the gantry rope size 12mm in diameter decreases the annoyance rate by around 4%, while narrowing the cross bridge interval decreases the annoyance rate by 2.14% at most. So enlarging the gantry rope size is more efficient than decreasing the cross bridge interval.

5. Concluding Remarks

Both the method based on ISO 2631-1-1997 and annoyance rate can evaluate the vibration comfort of the catwalk and reach a consistent result. However the latter one can give a quantitative result compared to the qualitative result given by the former one. Both enlarging the gantry rope diameter and reducing the cross bridge interval can

increase the comfort level of the catwalk during wind-induced vibration, while the latter one has minor effect.

Table 4 Calculation cases and results

Case No.	Cross bridge interval(m)	Gantry rope diameter (mm)	Frequency weighted RMS acceleration a_w (m/s^2)		Corresponding subjective response		Annoyance rate	
			y	z	y	z	y	z
1	185	48	1.02	1.05	uncomfortable	9.80%	11.87%	
2	185	54	0.99	1.02		7.40%	9.66%	
3	185	60	0.92	0.97		7.28%	7.72%	
4	164	60	0.88	0.95		7.24%	7.70%	
5	148	60	0.88	0.94		6.10%	7.13%	
6	93	60	0.87	0.92		5.63%	5.58%	

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