ASSESSMENT AND OPTIMISATION OF HUMAN WALKING AND TRAFFIC INDUCED VIBRATION OF FLOORS IN OFFICE BUILDINGS

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MY BELOVED FAMILY

(My husband Azizi, my son Hakimi and my daughter Fatini)

who are always behind me to give invaluable support and care during my critical time

my loving Chek and my siblings who are always support me

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ABSTRACT

Rapid development in office building construction and advanced technologies installed in sensitive structures such as high-tech equipment leads to requirements for very low levels of vibration and become more important in structural design. Therefore, this thesis presents an investigation of vibration criteria assessment and optimisation of the effect of low amplitude ground vibrations induced by human walking and traffic on the floors in office building. Two office buildings were chosen as the case study at two different places namely OB1 and OB2. Field measurement was carried out by using Laser Doppler Vibrometer (LDV100) to obtain vibration inputs. Vibration inputs were transferred into finite element analyses by using ANSYSv14 to simulate the structure dynamic response. MATLAB software also utilized to perform Vibration Criteria (VC) curve and plot. The results obtained were then checked against the generic VC curve from Gordon and Malaysia guidelines, to determine the vibration sensitivity level of each building. As a result, OB1 indicated under VC-A level due to vehicles at Singapore and OB2 at Malaysia fall under VC-E due to vehicles and increased to VC-C, VC-A and ISO level due to peoples walking. It is also showing which location on floor is suitable to accommodate the sensitive equipment, but not at the middle of the floor because of the peak response. After the modification process on structural elements such as slab thickness, beam and column sizes, and adding extra elements, the vibration response also changed either increased or decreased from the earlier VC curve and plot. OB1 shows almost similar vibration level under VC-A. While for OB2, it is also indicating similar response under VC-E. Therefore, from the iterative process in finite element modelling from the optimisation method, a VibroTable is proposed to be a new guideline or quick review to the client or structure analyst engineer to investigate the proper size of certain element of structure. The difference of vibration velocity values between Gordon and Malaysian guidelines were found, where Gordon guideline covers very low level of vibration effect, while Malaysian guideline only considers high level of vibration.

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ABSTRAK

Kemajuan pesat dalam pembinaan bangunan pejabat dan teknologi termaju dalam pembinaan bangunan sensitif yang berteknologi tinggi memerlukan tahap getaran yang sangat rendah dan menjadi semakin penting dalam merekabentuk struktur. Oleh itu, tesis ini menerangkan tentang penyelidikan ke atas penilaian kriteria getaran dan pengurangan kesan getaran tanah yang beramplitud rendah yang disebabkan oleh manusia yang berjalan dan kenderaan pada ruang lantai di dalam bangunan pejabat. Dua bangunan pejabat telah dipilih sebagai kajian kes di dua lokasi yang berbeza, iaitu OB1 dan OB2. Pengukuran di lapangan telah dijalankan dengan menggunakan *"Laser Doppler Vibrometer (LDV100)"* untuk mendapatkan input getaran. Input getaran ini dipindahkan ke analisis unsur terhingga menggunakan ANSYSv14 untuk proses simulasi tindakbalas dinamik struktur. Perisian MATLAB juga turut digunakan untuk menghasilkan lengkung dan plot kriteria getaran. Keputusan yang telah dihasilkan kemudian disemak dengan lengkung kriteria getaran generik berdasarkan garis panduan Gordon and Malaysia, untuk menentukan tahap kesensitivitian getaran pada setiap bangunan. Hasil keputusannya ialah, OB1 menunjukkan pada tahap VC-A yang disebabkan oleh kenderaan di Singapura dan OB2 di Malaysia berada pada VC-E disebabkan oleh kenderaan dan meningkat ke tahap VC-C, VC-A dan ISO berdasarkan kepada penghuni yang berjalan. Keputusan juga menunjukkan di mana lokasi yang sesuai di lantai, untuk diletakkan peralatan sensitif, tetapi tidak di tengah lantai kerana tindak balas puncak yang berlaku. Setelah proses pengubahsuaian pada elemen struktur seperti ketebalan papak, saiz rasuk dan tiang, dan penambahan elemen tambahan, tindak balas getaran juga berubah samada meningkat atau menurun daripada lengkung VC dan plot VC sebelumnya. OBI menunjukkan tahap getaran yang hampir serupa di bawah VC-A. Manakala untuk OB2, ia juga menunjukkan tindak balas yang sama di bawah VC-E. Oleh itu, daripada proses berulang pemodelan elemen terhingga ini daripada proses pengoptimuman, satu JadualGetar dicadangkan untuk menjadi garis panduan baharu atau semakan secara pantas kepada pemilik bangunan

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atau jurutera penganalisis struktur untuk menyiasat saiz yang tepat bagi sesuatu elemen struktur. Perbezaan nilai halaju getaran di antara garis panduan Gordon dan Malaysia telah ditemui, di mana garis panduan Gordon merangkumi tahap kesan getaran yang sangat rendah, manakala garis panduan Malaysia hanya mempertimbangkan tahap getaran yang tinggi.

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LIST OF SYMBOLS AND ABBREVIATIONS

[M]	-	mass matrix
[C]	-	damping matrix
[K]	-	stiffness matrix
$\{\ddot{u}\}$	-	nodal acceleration vector
$\{\dot{u}\}$	-	nodal velocity vector
$\{u\}$	-	nodal displacement vector
$\{F(t)\}$	-	load vector
C	-	viscous damping
Ct	-	moment-resisting frames
f	-	frequency (Hertz)
$\boldsymbol{f}$	-	footfall pace
f_n	-	natural frequency
$f(t)$	-	external loading
$F(t)$	-	vector of externally applied loads
$F(t)D$	-	vector of damping, or energy dissipation, forces
$F(t)_I$	-	vector of inertia forces acting on node masses
$F(t)S$	-	vector of internal forces carried by the structure
H	-	height of the building
I	-	unit vector
I_{eff}	-	effective impulse
k	-	stiffness of the spring
K	-	static stiffness matrix
L_n	-	modal earthquake excitation
m	-	mass
$\boldsymbol{m_n}$	-	scales storey masses by mode shape squared

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M	-	mass matrix
M_n	-	modal mass
N	-	number of degrees of freedom (DOF)
Nm	-	number of modes considered
T	-	time (second)
u_g	-	*ground displacement*
μ_i	-	mode shape coordinate corresponding to the point i where the impulse(footfall) is applied
μ_j	-	the mode shape coordinates corresponding to the point j where the impulse (footfall) is applied
$x(t)$	-	displacements
$x(t)_g$	-	free field ground displacements
$\dot{x}(t)$	-	velocities
$\ddot{x}(t)$	-	accelerations
v_i	-	particle velocity
v_i	-	maximum resultant velocity
v_x	-	vibration velocity in the X direction
v_y	-	vibration velocity in the Y direction
v_z	-	vibration velocity in the Z direction
v_{max}	-	vertical velocity
x	-	natural coordinates
Y	-	vector of modal amplitudes
Y_n	-	modal amplitudes
$\ddot{Y}_n(t)$	-	model acceleration response on the structure in mode *n*
ϕ	-	modal matrix
ϕ_n	-	mode shape
ω	-	number circular frequency [rad/s]
ω_n	-	radian frequency
ζ	-	damping ratio
λ	-	wavelength
γ	-	concrete density

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µm	-	micrometer
µm/s	-	micrometer per second
µm/sec	-	micrometer per second
mm	-	milimeter
mm/s	-	millimeter per second
mm/sec^2	-	millimeter per second square
m	-	meter
m/s^2	-	meter per second squared
kg	-	kilogram
kg/m^3	-	kilogram per cubic metre
N/m^2	-	Newton per square metre
kHz	-	kilohertz
km/h	-	kilometer per hour
in	-	inches
2D	-	two dimension
3D	-	three dimension
AFM	-	Atomic Force Microscope
BBN	-	Bolt Beranek and Newman’s
BRE	-	Building Research Establishment
BS	-	British Standard
DoE	-	Department of Environment
DIN	-	German Standard
E	-	Modulus Young
FE	-	Finite Element
FEA	-	Finite Element Analysis
FEM	-	Finite Element Modelling
FE-SEM	-	Field Emission Scanning Electron Microscope
FFT	-	Fast Fourier Transform
GUI	-	Graphical User Interface
H	-	Horizontal
Hz	-	Hertz

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OB1	-	Office Building 1
OB2	-	Office Building 2
IEST	-	Institute of Environmental Sciences and Technology
ISO	-	International Standards Organization
LDV	-	Laser Doppler Vibrometer
Max	-	Maximum
Min	-	Minimum
MRI	-	Magnetic Resonance Imaging
MDOF	-	Multi Degree of Freedom
MDOFs	-	Master Degree of Freedom
PPV	-	Peak Particle Velocity
PF	-	Participation Factor
R&D	-	Research and Design
RMS	-	Root-Mean-Square
SDOF	-	Single Degree of Freedom
SEMs	-	Scanning Electron Microscopes
T	-	Torsional
TFT-LCD	-	Thin Film Transistor Liquid Crystal Display
USBM	-	U.S. Bureau of Mines
UTHM	-	Universiti Tun Hussein Onn Malaysia
V	-	Vertical
VC	-	Vibration Criteria
ModalV	-	Modal Version
VSATs	-	Vibration Serviceability Analysis Tools

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