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Control of Lateral Forces on Industrial Steel Structures with Overhead Cranes

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Abstract

Industrial steel buildings with cranes are usually subjected to a series of lateral forces, including wind loads, frictional drag forces and force due to the impact of moving the bridge of the cranes inside the building. Since industrial steel structures are usually lightweight and low in profile, seismic forces may be relatively low and not taken into consideration. This study focused on limiting the impact of lateral forces on steel industrial building with cranes using a supplementary control system to the bracing system of the structure. The supplemental control system consists mainly of friction dampers called ring spring dampers to absorb input forces and to improve the performance of industrial steel structures exposed to lateral forces.The results showed that the proposed damping system reduces response and displacement of the structure significantly.

Keywords: industrial steel structures, lateral forces, overhead crane, crane impact, damper, bracing system, wind load.

I. INTRODUCTION

The overhead cranes, which are important parts of specialized equipment used in the handling of materials, are inevitably exposed to mechanical vibrations during operation. The weights of overhead cranes, lack of suspension damping systems, and other factors combine to ensure that crane operations are subjected to vibrations in the work environment. The objective of this study is to improve to performance of industrial buildings exposed to lateral forces by reducing the impact of loads due to thelongitudinal wind forces and fractional drag forcesas well as the impact of the crane as shown in figure 1.

By installing friction dampers in the bracing system of the structure, lateral forces are transferred through the system and the dynamic energy is absorbed by the frictionsurfaces between them rubbing against each other.In this study, asteel structure with an overhead crane is considered and the analysis is performed according toAustralian and New Zealand standards.The dimensions, general layout and other characteristics were chosen to be representative of a building for which the use of bracing and dampers system was a reasonable solution.

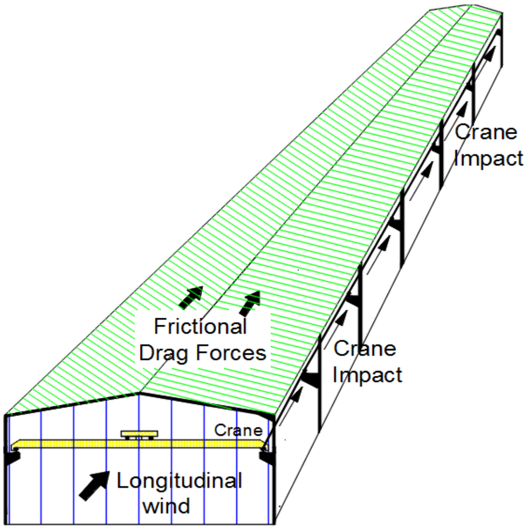


Fig. 1: industrial steel building exposed to longitudinal forces.

II. CRANE LOADS

Industrial buildings are generally equipped with overhead cranes, which run on rails supported by the building structure as shown in figure 2.

The loads imposed by these cranes must therefore be allowed for. Three principle types of forces induce a complex pattern of stresses in the upper part of the crane girder and the structural framing of the building.

A) Vertical Loads

vertical crane loads are termed as wheel loads. The maximum wheel loads are the sum of:

1) the weight of the trolley (carriage) and liftedload.
2) plus, the weight of the crane bridge and the weight of the crane girder and the rails.

B) Lateral Load (Side Thrust)

lateral crane loads are oriented perpendicular to the crane runway and are applied at the top of the rails.

Lateral loads are caused by:

1) acceleration and declaration of the trolley and loads.
2) non- vertical lifting.
3) unbalanced drive mechanisms.

Most specification and model building codes set the magnitude of lateral loads at 20% of the sum of the weights of the trolley and the lifted load.

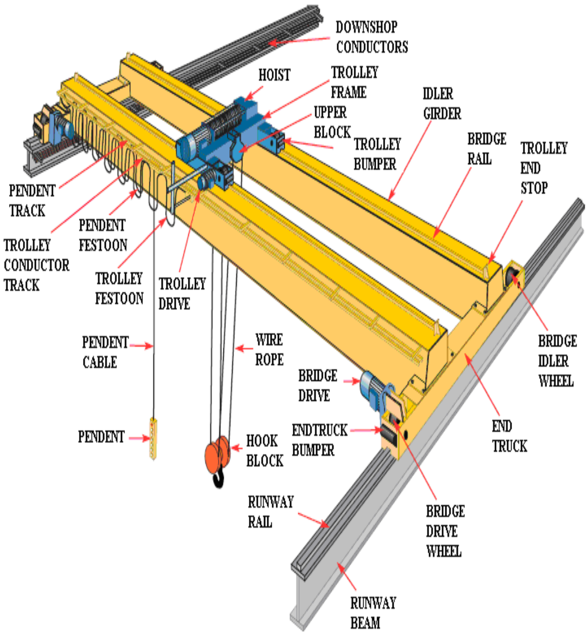


Fig. 2: double girder crane on runway between building frames

C) Longitudinal Forces

(traction andbumper impact loads) - longitudinal crane forces are due to either acceleration or deceleration of the bridge crane or the crane impacting the bumper as shown in figure 3.

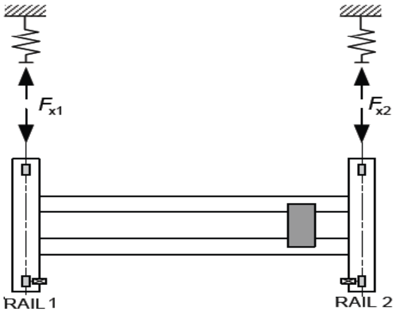


Fig. 3:force configuration during buffer impact.

1) Tractive forces – are limited by the coefficient of friction of the steel wheel on the rails.
2) Impact load – is the longitudinal force exerted on the crane runway by a moving crane striking the end stop. The impact force is a function of the length of the stroke of the bumper and the velocity of the crane upon impact with the crane stop.

The longitudinal forces are normally provided by the crane manufacturer. If this information is not available, the AISE technical report as a guide for the design and construction of mill buildings [13], provides equations that can be used for determining the bumper forces. If the number of the driven wheels is unknown, the tractive force as 10% of the total wheel loads.

TABLE I
Technical capacity of 10-ton crane [4]

Technical Parameter					
Model	**Capa-city (t)**	**Trolley Weight (kg)**	**Span (m)**	**Crane Weight (kg)**	**Crane Rails (kg)**
LD10	10	650	10.5	3230	24
			13.5	3910	24
			16.5	5300	24
			19.5	6230	24
			22.2	7120	24
			25.5	8940	38
			28.5	10730	38

III.WIND LOADS

The Australian / New Zealand Standards wind actions AS/NZS 1170.2:2002 [1], is adopted in this study to determine the wind and friction drag forces. The design wind pressure and distributed forces can be obtained for design wind pressure

$$P = 0.5\, \rho_{air}\, [V_{des,\theta}]^2 C_{fig}\, C_{dyn} \quad (1)$$

where:
P = design wind pressure acting normal to surface, in Pascal.
ρ_{air} = density of air, which shall be taken as 1.2 kg/m^2
$V_{des,\theta}$ = building orthogonal design wind speeds (usually, θ= 0, 90°, 180° and 270°).
C_{fig} = aerodynamic shape factor.
C_{dyn} = dynamic response factor (the value is 1.0 except where the structure is wind sensitive) i.e. a natural frequency less than 1 Hz.

IV. FORCES DELIVERED FROM FRICTIONAL DRAGE

The frictional drag force coefficient C_f ranges from 0.01 to 0.04 depending on the roughness of the surface.

Unlike the pressure coefficient, C_f is used to calculate forces parallel to the building surface.

To determine wind actions, the forces (F) on a building element, such as a wall or a roof, shall be the vector sum of the forces calculated from distributed frictional pressures applicable to the assumed area, as follows:

$$F = \sum (f_z . A_z) \quad (2)$$

Where:

f_z = the design frictional distributed force parallel to the surface.

C_{fig} is used to give a frictional drag on external surfaces of the structure only. Load per unit area acts parallel to the surface.

$$C_{fig} = C_f k_c (3)$$

The aerodynamic shape factor (C_{fig}) for calculating frictional drag effects on hoardings and walls, where the wind is parallel to the hoarding or wall, shall be equal to C_f, which shall be determined as shown in the Table 2.

TABLE II
Friction drag coefficient [1]

Surface Description	C_f
Surfaces with ribs across the wind direction.	0.04
Surfaces with corrugations across the wind direction.	0.02
Smooth surfaces without corrugations or ribs or with corrugations or ribs parallel to the wind direction.	0.01

V. CALCULATING THE EXTERNAL AND INTERNAL PRESSURES

The values of external coefficient C_{pe} vary over the external surface of the building and depend on the structure's shape and the orientation of the surface relative to the wind. For example, the windward wall generally has C_{pe} = +0.7, while the side walls near the windward end of a building have C_{pe} = -0.65, reference [1]. The design external pressure at a given point depends not only on the site wind speed and the external pressure coefficient, but also on the four factors k_a , k_c , k_l and k_p which are area reduction factor, combination factor, local pressure factor and porous cladding reduction factor respectively, and are not considered in this research.

The internal pressure coefficient C_{pi} , may be either positive or negative, depending on the location of openings relative to the wind. For buildings with open interior plan, C_{pi} , is assumed to be the same on all internal surfaces of an enclosed building at any given time.If there is just one dominant opening, C_{pi} , corresponds to thejust one dominant opening, C_{pi} , corresponds to the external pressure coefficient C_{pe} , that would apply on the face where the opening is located. Thus, for example, a shed with one end open will experience C_{pi} = +0.7 when the wind blows directly into the open end, and C_{pi} = -0.65 for a cross wind. If the building is enclosed or has opening distributed around faces which have bothpositive and negative external pressures, internal pressure coefficients are smaller.

VI. CALCULATING THE TOTAL LONGITUDINAL LOADS ON INDUSTRIAL STRUCTURE.

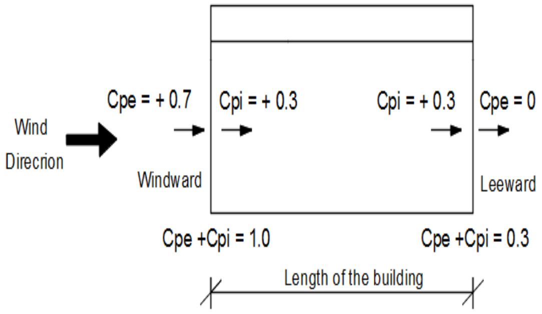


Fig.4: external and internal wind coefficients.

Figure 4 shows the external and internal wind coefficients for windward and leeward walls of the building. The total external and internal coefficients on windward and leeward are equal to 1.3. As per Australian and New Zealand standard AS/NZS 1170.2 [1], the wind speed on steel structure with a crane should not be greater than 30m/sec. The wind pressure P on the structure can be obtained from Eq.1 and equals to 1.1 kPa.

VII. CRANE IMPACT LOAD

The crane impact load can be obtained as mentioned in section 2, and equals to 0.1 * total weight of the crane load.

F (KN)	S_e (mm)	W_e (j)	h_e (mm)	D_1 (mm)
350	3.7	648.0	20.0	166.0
510	3.9	995.0	22.4	198.0

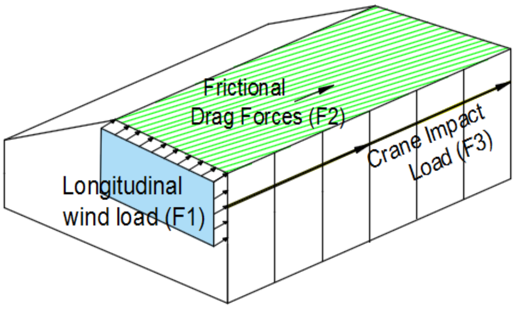


Fig. 5:longitudinal loads applied on the structure

From figure 5, it can be seen that the total longitudinal load on the structure is equal to sum of three forces F_1,F_2 and F_3.

where:
F_1 = longitudinal wind load.
F_2 = friction drag forces.
F_3= crane impact load.

VIII. PROPOSED RING SPRING DAMPERS

Ring spring dampers have some features and characteristics that make them very useful as lateral control devices. Ring spring dampers are constructed of steel materials in which no possible leakage of liquid and no refilling or maintenance of any of the parts is needed which are potential problem in the viscous fluid dampers. Ring spring dampers absorb large amounts of the input energy with low weight and small size which is in contrast to viscous fluid dampers. However, viscous fluid dampers do not increase the stiffness of the structure and consequently the accelerations of the structure and its contents.

The proposed damper-bracing system is composed of two major components, a bracing with high axial stiffness and a damper device located at the bottom of the main column. The proposed system is consisting of two main components. A steel hollow section member is used to transfer the tension forces to the damper and the damper device to overcome the tension force and hence reduces the lateral displacement of the structure to the allowable values.

The damper device which may be used is called ring spring damper. The device is a passive energy dissipater based on half-centering friction mechanism.

Ring springs are frictional devices consisting of inner and outer rings that have tapered mating surfaces as show in figure 6. As the spring column is located in compression or tension, the axial displacement is accompanied by sliding of the rings on the conical friction surfaces. The outer rings are subjected to circumferential tension and the inner rings experience compression.

TABLE III
Details of ring springs forces and dimensions[11].

TABLE III – CONTINUE
Details of ring springs forces and dimensions

d_1 (mm)	b/2 (mm)	D_2 (mm)	d_2 (mm)	G_e (kg)
134.0	16.0	170.0	130.0	0.822
162.0	18.5	203.0	157.0	1.515

where:
D_1,d_1 = outer and inner diameter of the rings coefficient.
D_2, d_2= outer and inner diameter of the guide components.

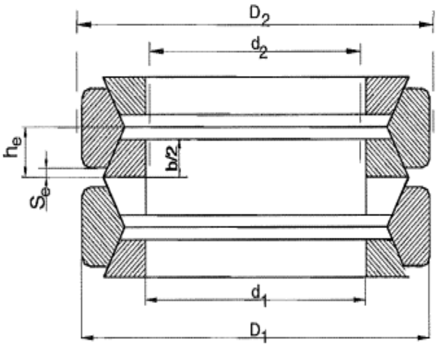


Fig. 6: prototype ring springs [11].

$b/2$= half width of ring
Ge = element weight
We = energy absorption (work for one element)
he =element height
Se =spring travel for one element

IX. NUMERICAL EXAMPLE

In order to interpret the applicability of the damping system in reducing the lateral forces for the industrial steel structures, the paper presents an example of determining the lateral forces applied on the structure. Generate the steel structure for the following design parameters: span = 25 m, height to runway beam of the crane = 7.5 m, eave height = 9 m and the total height of the column is 10.25 m. The spacing of the frame columns = 7.5 m, the number of

bays = 10 bays and the total length of the building is 75 m.
The capacity of the overhead crane in the building is 10 ton and the data for the crane loads obtained from table 1 (the technical capacity of 10-ton crane). The trolley weight = 6.5 kN and the crane weight = 89.4 kN.

SOLUTION

Calculate the three major longitudinal forces:

- Longitudinal wind load.
- Friction drag forces.
- Longitudinal crane impact.

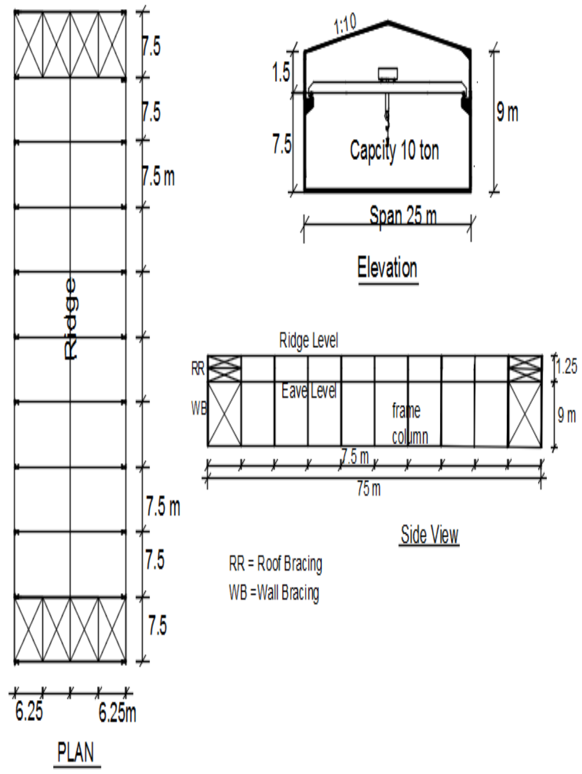


Fig. 7: three views of the structures with overhead crane.

1. *Longitudinal wind load*

The wind coefficients for windward and leeward are equal to:
for windward wall:Cpe = 0.7, Cpi = 0.3,
Cpe + Cpi = 1.0
for leeward wall: Cpe = 0.3, Cpi = 0,
Cpe + Cpi = 0.3
The total longitudinal wind coefficient = 1.3

The wind velocity for industrial steel structure with crane does not exceed than V = 30m/sec, the design wind pressure (equation 1) is equal to:

$$P = 0.5\,\rho_{air}\,[V_{des,\theta}]^2 C_{fig}\,C_{dyn}$$

where:
ρ_{air} = density of air and shall be taken equals to 1.2 kg/m^3 and $C_{fig}\,C_{dyn} = 1$
P = 0.5 * 1.2 * 30^2*10^{-3}= 0.54 kN/m^2
the tributary area = 12.5 * 5.12 = 64 m^2
the longitudinal forces on one side of the structure = 0.54 * 64 = 34.6 kN

2. *Friction drag forces*

The roof surface of one side of the structure is equal to 75 * 12.5 = 937.5 m^2,
friction drag coefficient = 0.04
The friction drag force = 0.54*937.5*0.04 = 20.25 kN

3. *longitudinal crane impact*

From table 1, for capacity of the crane = 10 ton,
the trolley weight = 650 kg,
the crane weight = 8940 kg
the total weight = 95.9 kN
The total longitudinal load on the structure is sum of longitudinal wind plus friction drag plus crane impact and equals to 150.75 kN at the level of the crane.

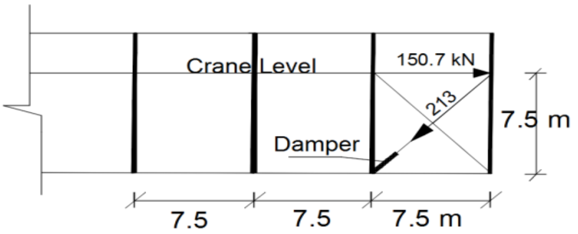


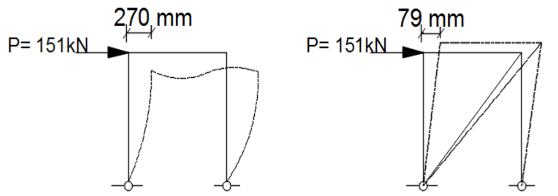
Fig. 8: axial force in the damper

From figure 8, the diagonal force in the bracing and damper is equal to 150.75/cos 45 = 213.2 kN.

The suitable damper size for this case can be chosen from table 3. A device with capacity equals to 350 kN and diameter of 16.6 cm is chosen.

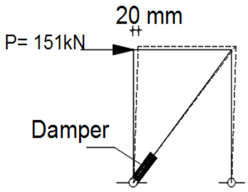
The performance of the frame of the structure under applied lateral loads was carried out in three cases as follows:

a) the frame without bracing system.
b) the frame with bracing.
c) the frame with bracing and damper.



a) Frame without bracing

b) Frame with bracing



c) Frame with bracing and damper

Fig. 9: the lateral displacement with and without damper

Figure 9 shows the lateral load on the frame structure in three cases. Structural analysis was carried out using structural analysis software [12]. The cross section of the main steel column is 460UB67, the steel cross section of the steel cross section of the bracing is SHS 50 x 5mm. By applying the lateral force of 151 kN at the eave level of the structure, the lateral displacements of the steel frame structure with and without the supplemental damping is shown in figure 9.

The lateral displacement of the structure under applied lateral load and without using bracing system in the structure is equal to 270 mm. By using diagonal bracing, the displacement is reduced to 79 mm at the top of the structure. Adding the supplemental friction damper to the structure reduced the lateral response of the structure to 20 mm at the top level of the structure.

X. CONCLUSION

This paper investigates the influence of the longitudinal forces on steel industrial structures with overhead cranes. The major three lateral forces of longitudinal wind forces, friction drag force and impact of moving the overhead crane in the building has been shown and calculated according to Australian/New Zealand standards.The study shows an alternative system of the traditional bracing system to reduce the impact of the forces on the structure. The paper has focused on the effect of using supplemental damping system in reducing the response of the structure under the effect of the longitudinal forces. The displacements and deformations of the structure can be greatly reduced without the need of increasing the stiffness and the member sizes of the primary structure or bracing member sizes. The dynamic response of the structure was controlled with adding damping by using the supplemental damping system to minimize the effect of forces produced by the wind loads and the overhead cranes and to reduce the displacement of the structure.The incorporation of supplemental damping devices in the form of ring spring dampers provides the opportunity to move damage away from the primary structural elements.A case study of steel buildingwith crane has been included to demonstrate the benefits of supplemental system in terms of controlling the displacement in the structures.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Australian / New Zealand Standard AS/NZS 1170.2:2002 - Structural design actions part 2: wind actions.

[2] S.T.Woolcock, M.A.Bradford, “Design of Portal Frame Building”, Third Edition 1999, Australian Institute of Steel Construction.

[3] J. D. Marshall, F. A Charney, “A hybrid passive control device for steel structures” Journal of Constructional Steel Research 66 (2010) 1287 – 1294.

[4] Cliftin website “overhead crane products” [Online] available: http://cliftion.com

[5] Z. Zhang, D. Chen, M Feng, “Dynamics Model and Dynamic Simulation of Overhead Crane Swing Systems Based on the ADAMS”, 2008 IEEE.

[6] H.-L. Hsu, H. Halim, “Improving seismic performance of framed structures with steel curved dampers”, Engineering Structures vol.130 (2017) pp 99-111.

[7] A. Benavent–Climent, “A brace-type seismic damper based on yielding the walls of hollow structural section”, Engineering Structures Journal Vol. 32 (2010) pp1113-1122.

[8] J.Tat, J. Finnegan & G. Sidwell, “A low damage Design Solution for a 15 Storey Steel Framed Building”, New Zealand Socity for Earthquake Engineering Conference, NZSEE 2013.

[9] Stojan Kravanja, Goran Turkalj, Simon Silih, “Optimal design of single-story steel building structures based on parametric MINLP optimization”, Journal of Constructional Steel Research vol. 81, Feb. 2013, pp 86-103.

[10] C. Adin, Praveen J.V, “Dynamic Analysis of Industrial Steel Structure by using Bracing and Dampers under Wind Load and Earthquake Load”, International Journal of Engineering Research & Technology (IJERT) Vol. 5 Issue 07, July 2016.

[11] RINGFEDER GmbH, Friction Springs, Ringfeder in Mech. Eng., Report R60E, Ringfeder Corporation, Germany.

[12] Microstran software for the analysis and design of 2-D and 3-D frames and Trusses.

[13] AISE Technical Report No.13–2003, “Guide for the design and Construction of Mill Building”, Association of Iron and Steel Engineers, Pittsburgh, Pennsylvania 15222.

[14] Amedeo Benavent-Climent, “A brace-type seismic damper based on yielding the walls of hollow structural sections”, Engineering Structures Journal vol.32 (2010) 1113-1122.

[15] H.-L. Hsu, H. Halim, “Improving seismic performance of framed structures with steel curved dampers”, Engineering Structures Journal vol.130 (2017) 99-111.

[16] Nagui W. Bishay-Girges, Athol J. Carr, "Ring Spring Dampers: Passive Control System for Seismic Protection of Structures", Bulletin of the New Zealand Society for Earthquake Engineering, Vol.47, No3, September 2014.

[17] VajreshwariUmachagi, Katta Venkataramana, G. R. Reddy, "Application of dampers for vibration control of structures", International Journal of Research in Engineering and Technology conference issue, Nov.2013.

[18] Chandrashekhar B Adin, Praveen J. V, "Dynamic Analysis of Industrial Steel Structures by using Bracing and Dampers Under Wind and Earthquake Load", International Journal of Engineering Research & Technology, Vol 5. Issue 07, July 2016.

[19] S.M Gledhill, G.K.Sidwell," The Damage Avoidance Design o Tall Steel Frame Building", New Zealand Society for Earthquake Engineering, 2008 NZSEE Conference.

[20] BrankoGorenc, Ron Tinyou, Arun Syam, "Steel Designers' Handbook", Seventh edition 2009, UNSW Press Book, Sydney, NSW2052, National Library of Australia.