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Validation of on-site job-built guardrails with shoring jack as supports

Evaluación de barandillas de seguridad de obras apoyadas en puntales

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ABSTRACT

To protect themselves against fall hazards in a slab-column frame, workers use the row of shoring jacks installed at 1 m from the edge as supports for on-site built guardrails. Inspectors of the Quebec Workers Compensation Board (*Commission de la santé et de la sécurité du travail* (CSST)) have expressed concern about the safety and compliance of these on-site built guardrails with the Quebec Safety Code for the Construction Industry (S-2.1, r.4). Some workers have also inquired if the shoring jack can be used as an anchor for a travel restraint system. The present study describes how an evaluation method and a test protocol have been used to verify if guardrails built on-site, with shoring jacks as supports, are safe and comply with the requirements of S-2.1, r.4 and if the shoring jack can be used as an anchor point for a travel restraint system. The results of the study show 1) guardrails built on site with shoring jacks as supports, are safe and comply with S-2.1, r.4 and 2) shoring jacks used as supports for guardrails must not be used as an anchor for a travel restraint system.

Keywords: Guardrails; shoring jacks; fall hazards; test protocol; anchor.

RESUMEN

Para la protección contra el peligro de caída en altura durante la ejecución de la estructura de un edificio, los trabajadores utilizan puntales acodalados a dos forjados y situados a 1 metro del borde de forjado como apoyo de las barandillas de seguridad. Inspectores de la Quebec Workers Compensation Board (Comisión de la santé et de la sécurité du travail (CSST)) han expresado su preocupación por la seguridad y el cumplimiento de estos sistemas de protección en la construcción conforme al Código de Seguridad de Quebec para la industria de la construcción (S-2.1, R.6). Así mismo algunos trabajadores han mostrado su inquietud sobre la utilización de los puntales como sistemas para limitar el desplazamiento. El presente estudio describe un método de evaluación y un procedimiento de ensayo que se han utilizado para verificar si las barandillas de seguridad apoyadas en puntales acodalados son seguras y cumplen con los requisitos de S-2.1, R.6; y si el puntal acodalado puede ser utilizado como punto de anclaje del sistema para limitar los desplazamientos. Los resultados del estudio muestran 1) las barandillas de seguridad apoyadas en puntales acodalados son seguras y cumplen con S-2.1, R.6 y 2) los puntales acodalados utilizados como apoyo de las barandillas de seguridad no deben ser usados como apoyos para sistemas con desplazamientos limitados.

Palabras clave: *Barandillas de seguridad; puntales; caídas en altura; procedimiento de ensayo; anclaje.*

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1. INTRODUCTION

The construction of cast in place reinforced concrete structures is fundamentally one of most economical systems of construction (1). A building technique frequently used consists of erecting the column-slab frame and then carry out the finish work at each floor as the construction progresses. This method of construction involves formwork reuse. At each floor, after the slab has been cast, formwork and shoring jacks have to be kept in place long enough to allow the concrete to develop sufficient strength to prevent hairline cracks or failure in the concrete. Local codes, job specifications or an engineer's approval give guidance for the minimum time before formwork and shoring jacks can be removed.

American Concrete Institute (ACI) recommends form's removal when concrete has reached at least 70 % of its design strength (2), that is, after 3 to 5 days. After stripping the slab, formwork and shoring jacks are reused for the next floor. Shoring jacks allow concrete to reach its full strength. This prevents excessive sag, distortion, cracking and/or other damage from occurring to the new slab. Workers can also start erecting formwork for the next floor.

As the construction progresses rapidly, with fall hazards at each floor, fall protection has to be implemented to protect the workers (3) (4) (5). With flat floors, guardrails are the most appropriate means of fall protection (6). They allow mobility and they exempt workers from wearing a harness and avoid the installation of anchors for workers' lanyards. Workers use the row of shoring jacks near the perimeter as supports to install on-site built guardrails made of prefabricated wooden or metal frames. This is a common practice in North America (7). However, during their site visits, inspectors of the Quebec Workers Compensation Board (CSST) have expressed concern during interviews about the safety of these on-site built guardrails and their compliance with existing regulations (6). Also, because shoring jacks are strong and can resist accidental loads in any direction, some workers have inquired if they can be used as anchors for a travel restraint system.

2. OBJECTIVES OF THE STUDY

The objectives of the present study are the followings :

- Verify if guardrails with shoring jacks as supports, built on-site, are safe and comply with the requirements of S-2.1, r.4 to ensure workers adequate fall protection;
- Determine the compressive (tightening) force in a shoring jack snugged up between a floor and a ceiling with a handmade tool to ensure the safety of a shoring jack as a support of guardrail;
- Determine the friction force of the shoring jack/concrete slab and the coefficient of friction of plywood-concrete;
- Verify if the shoring jack can be used as an anchor for a travel restraint system.

3. METHODS FOR STUDYING GUARDRAILS WITH SHORING JACKS AS SUPPORTS

The methods for studying guardrails with shoring jacks as supports entail the following steps:

(i) Observation of Metropolitan Montreal sites to collect geometrical characteristics of guardrails with shoring jacks as supports;
(ii) Interviews and discussion with occupational and safety (OHS) coordinators;
(iii) Application of the evaluation method and test protocol developed in a previous study (6) to verify if on-site built guardrails with shoring jack as supports are safe and comply with S-2.1, r.4;
(iv) Laboratory tests to evaluate the strength of guardrails and to determine the friction coefficient plywood plate-concrete;
(v) Determination of the compressive (tightening) force in a shoring jack used as support for guardrails;
(vi) *In situ* tests by applying the loads specified by S-2.1, r.4 on reconstructed guardrails in the laboratory;
(vii) Analysis of the results and formulation of recommendations.

4. CONSTRUCTION SITES OBSERVATIONS

While observing guardrails with shoring jacks as supports in Montreal sites, we realized quickly that with the numerous parameters to be considered, among others, the type and the state of materials used, the construction and the quality of construction and the conditions and nature of the anchors, it was not appropriate to use classical methods of strength of materials or finite elements methods to verify them. Instead, the simplest and fastest method to study these guardrails is to carry out *in situ* tests by applying the loads specified by S-2.1, r.4. With production constraints and safety issues involved on sites, it was decided to reconstruct the guardrails in the laboratory, as built on sites. The tests would then be carried out safely on these reconstructed guardrails.

5. MAIN FINDINGS OF CONSTRUCTION SITES OBSERVATIONS

The main findings of our construction sites observations are:

1) The shoring jacks used as supports for guardrails are those usually used for concrete formwork (Figure 1). They are generally 2 to 4 metres long, capable of withstanding loads of 12 to 40 kN (2500 to 9000 pounds). Infrastructure Health & Safety Association (IHSA) recommends being careful when using shoring jacks because over-tightening may develop high forces which may damage green concrete.
2) The shoring jack observed on site is made up of an inner tube about 2 m long that slides in an outer tube about 2.2 m long. Both inner and outer tubes are fitted at their ends with a metal plate with a hole at the centre. Holes at 152.40 mm (6 inches) c/c and a locking screw at the centre of the shoring jack enables to vary and to adjust its height to fit snugly between a floor and a ceiling (Figure 1). On site, the shoring jacks are fitted with plywood softener plates top and bottom to avoid damaging green concrete and slipping. The plywood plate has a 4 inches nail at the centre which slides in the hole of the shoring jack end plates.

On site, workers installed rows of shoring jacks between the floor and the ceiling. Near the perimeter, the row of shoring jacks is installed at 1.83 m (6 ft) centre to centre, about 1 m from the edge with a special handmade tool to tighten them. Two types of guardrail frames were used: 1) a safety fence made of a metal frame holding a wire mesh panel (Figure 2 (a)) and 2) a wooden frame of 38 × 89 mm (2 × 4), 1.2 m (4 ft)

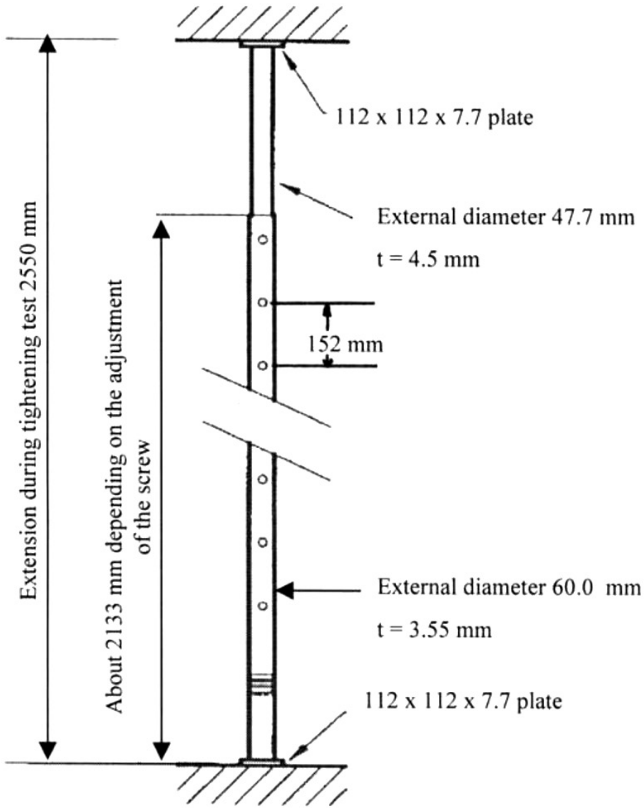


Figure 1. Typical shoring jack.

high by 2.4 m (8 ft) long (Fig.2 (c)). The frames are installed on the inside of the shoring jacks by overlapping them two feet on the shoring jacks and tieing them with rebar wire # 16. At the end of our site observation, a guardrail made up of a wooden frame of 38 × 89 mm (2 × 4) used on several residential buildings was selected to undergo laboratory testing (Figure 2 (c)). It was the best built and the most promising to be tested in the laboratory.

6. RESISTANCE AND CONSTRUCTION REQUIREMENTS OF S-2.1, R.4.

6.1. Resistance

1) A guardrail shall be designed to:
   (a) resist a concentrated horizontal force of 900 newtons (202 lb) applied to any point of the top plate; and
   (b) resist a concentrated vertical force of 450 newtons (101 lb) applied to any point of the top plate.
2) Where there is a concentration of workers, as well as other areas where a guardrail may be submitted to unusual pressures, the guardrail shall be reinforced accordingly.
3) Where equipment or materials may fall from one work level to another, precautions shall be taken to avoid this, unless there is a guardrail strengthened for this purpose.

6.2. Construction:

1) Any guardrail shall be between 1 metre and 1.2 metre above the surface on which the worker is working.
2) A wooden guardrail shall consist of:
   (a) top plate not less than 40 millimetres thick by 90 millimetres wide, supported on posts of the same dimension spaced at intervals of not more than 1.8 metres and placed so that the 90 millimetres width of the post is on the axis of the width of the top plate;
   (b) an intermediate rail not less than 75 millimetres wide at midway and securely fastened to the inner side of the posts; and
   (c) a toe-board at least 90 millimetres high and securely fastened to the inner side of the posts.
3) A guardrail of steel wire ropes shall be maintained rigid by means of a turnbuckle and consist of:
   (a) a wire rope at least 10 millimetres in diameter for the top-rail and the intermediate rail;
   (b) steel posts spaced at intervals of not more than 3 metres; and
   (c) a toe-board of at least 90 millimetres high and securely fastened to the inner side of the posts.

7. TEST PROTOCOL

The test protocol to verify the guardrails compliance with S-2.1, r.4 has been developed in a previous study (8). It consists of static and dynamic tests. Table 1 describes the static tests 1 to 4 corresponding to the most critical loading cases determined by structural analysis of the resistance requirements of S-2.1, r.4. Test 1 verifies the resistance of the post, Test 2 verifies the resistance of the top rail and Tests 3 and 4 verify the membrane effect and the resistance of a multiple

Figure 2. (a) Metal frame holding a wire mesh as guardrail; (b) Casting of slabs; (c) Wooden frame of 38 × 89 mm (2 × 4) as guardrail.

spans guardrail. If the guardrails fulfill the static tests of the protocol, they will comply with S-2.1, r.4.

Table 2 describes the dynamic tests 5 to 8 adapted from the Institut National de Recherche et de Sécurité (INRS) to verify the guardrail's capacity to retain a 100-kg (220-lb.) wooden torso hitting the top rail at a speed of 2 m/s (7 ft./s) (9). In his tests, Bobick (10) uses a test manikin falling against the top rail that generates an impact force of 198 kg (435 lb). The dynamic tests simulate the fall of a worker moving backwards or moving rapidly towards a guardrail. S-2.1, r.4 does not require theses dynamic tests.

8. LABORATORY TESTS

The tests were carried out at the Structural laboratory of the École Polytechnique in October 2001 according to the test protocol (11). The set-up consisted of anchoring guardrails on concrete slabs according to various configurations planned in the test protocol. These guardrails were reconstructed in the laboratory as on construction site. The shoring jacks (Figure 1) and the prefabricated wooden frames (Figure 2 (c)) were purchased from the contractor "Les Coffrages Dominic" of Montreal who use them for formwork jobs on its Quebec construction sites.

Concrete slabs were built to reproduce the same conditions as in buildings where guardrails were installed. The large slab simulated the work floor while the four small slabs simulated the ceiling. It was 6.10 m (20 ft.) long, 0.762 m (30 in.) wide, and 203.2 mm (8 in.) thick to enable three guardrail spans 1.83 m (6 ft.) long to be installed (Figure 2 (b)). The small slabs were 762 mm (30 in.) long, 304.8 mm (12 in.) wide and 203.2 mm (8 in.) thick. The concrete used for the slabs had to have a compressive strength f'_c simulating the slabs on which guardrails are installed on construction sites. The average compressive strength of the concrete produced in the École Polytechnique de Montréal's structures laboratory was 29 MPa. The reinforcement used in the slabs corresponded to minimum reinforcing bars $A_{s,min}$ of a building slab as prescribed in CSA-A23.3-10 – Design of concrete structures (12), namely 0.2% in each direction.

Table 1. Verification of the resistance requirements of section 3.8.2 of S-2.1, r.4.

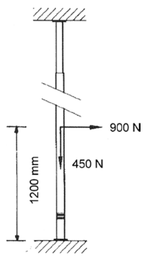
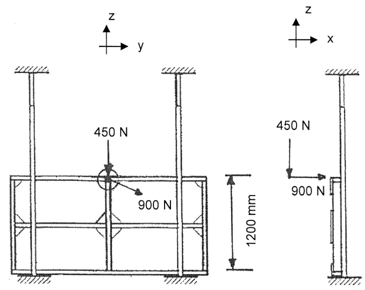
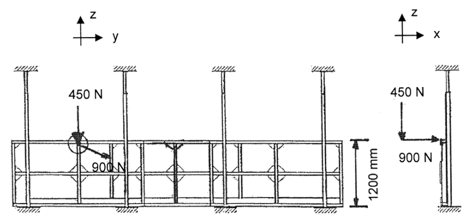
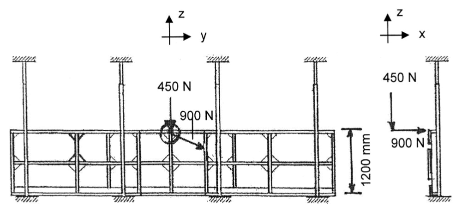
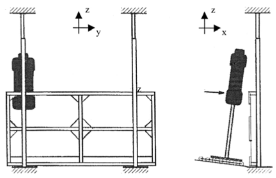
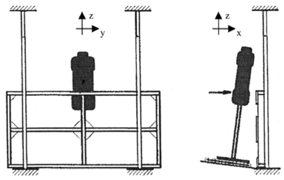
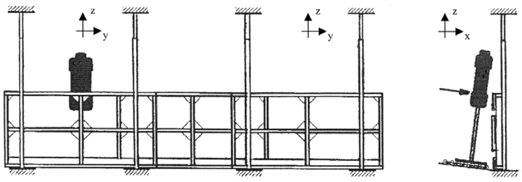
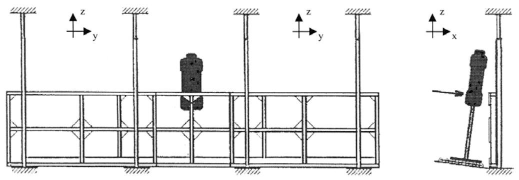
Test	Description of the test	Diagram of the test	No. of tests	Parameters to be measured and observations
1	Loads of 900 N (202 lb.) horizontal and 450 N (101 lb.) vertical applied simultaneously on a post as anchored on construction site.	 Schematic figure of test 1.	3	• measurement of deflection to plot the force vs deformation graph; • measurement of the deflection at 900 N (202 lb.); • measurement of the maximum deformation at the base of the post by a strain gauge (1 test/3 tests); • observation of the behaviour of the post under load.
2	Loads of 900 N (202 lb.) horizontal and 450 N (101 lb.) vertical applied simultaneously at mid-span of the top rail of one section of guardrail anchored as on the construction site.	 Schematic figure of test 2.	1	• measurement of the deflection; • measurement of the maximum deformation at the critical points of the guardrail by strain gauges; • observation of the behaviour of the section of the guardrail under load.
3	Loads of 900 N (202 lb.) horizontal and 450 N (101 lb.) vertical applied simultaneously on the top rail at mid-span of the end span of a series of three sections of guardrail anchored as on the construction site.	 Schematic figure of test 3.	1	measurement of the deflection; measurement of the maximum deformation at the critical points of the guardrail by strain gauges; observation of the behaviour of the section of the guardrail under load.
4	Loads of 900 N (200 lb.) horizontal and 450 N (100 lb.) vertical applied simultaneously on the top rail at mid-span of the central span of a series of three sections of guardrail anchored as on the construction site.	 Schematic figure of test 4.	1	measurement of the deflection; measurement of the maximum deformation at the critical points of the guardrail by strain gauges; observation of the behaviour of the section of the guardrail under load.

Table 2. Dynamic tests (adapted from INRS).

Test	Description of the test	Diagram of the test	No. of tests	Parameters to be measured and observations
5	A 100-kg (220-lb.) wooden torso hits the post of one section of guardrail anchored as on the construction site at a speed of 2 m/s (7 ft/s).	 Schematic figure of test 5.	1	• measurement of deformations xx, yy, zz with displacement transducers; • pictures taken with the high speed camera; • capacity of the post to retain the wooden torso without breaking or releasing the load; • observation of the behaviour of the post under the impact force.
6	A 100-kg (220-lb.) wooden torso hits the centre of the top rail of one section of guardrail anchored as on the construction site at a speed of 2 m/s (7 ft/s).	 Schematic figure of test 6.	1	• measurement of deformations xx, yy, zz with displacement transducers; • pictures taken with the high speed camera; • capacity of the guardrail to retain the wooden torso without breaking or releasing the load; • observation of the behaviour of the section of the guardrail under the impact force.
7	A 100-kg wooden torso hits the centre of the top rail of the end section (left or right) of a series of three sections of guardrail anchored as on the construction site at a speed of 2 m/s (7 ft./s).	 Schematic figure of test 7.	1	• measurement of deformations xx, yy, zz with displacement transducers; • pictures taken with the high speed camera; • capacity of the guardrail to retain the wooden torso without breaking or releasing the load; • observation of the behaviour of the section of the guardrail under the impact force.
8	A 100-kg wooden torso hits the centre of the top rail of the central section of a series of three sections of guardrail anchored as on the construction site at a speed of 2 m/s (7 ft./s).	 Schematic figure of test 8.	1	• measurement of deformations xx, yy, zz with displacement transducers; • pictures taken with the high speed camera; • capacity of the guardrail to retain the wooden torso without breaking or releasing the load; • observation of the behaviour of the section of the guardrail under the impact force.

The wooden frames were made of usual Spruce-Pine-Fir (SPF) 40 × 90 mm (2x4 nominal) purchased in hardware superstores (Figure 2 (c)). The geometrical and mechanical characteristics of wood are specified by the Canadian Wood Council (13).

9. SHORING JACK CALIBRATION CHART

A shoring jack was fitted with strain gauges and calibrated by the Amsler hydraulic press (Figure 3). The calibration chart of load/mean strain was then plotted. By fitting similar shoring jacks with strain gauges and measuring the strains during laboratory tests, this calibration chart was used to determine the compressive forces in the shoring jacks.

10. STATIC TESTS-SERIES 1

Test 1-1: Determination of the compressive (tightening) force in a shoring jack

Tests 1-1a, 1-1b and 1-1c were carried out with similar shoring jacks fitted with strain gauges. With a handmade tightening tool, 300 mm long, the technician turned the shoring jack's adjusting screw by a fraction of turn (rotation) and the corresponding strain was recorded. With the calibration chart, the force generated in the shoring jack can be read directly by entering the mean strain. This step by step tightening was

Figure 3. Calibration of a shoring jack with the Amsler press.

carried out until the screw jammed; this gives the maximum compressive force in the shoring jack (Figure 4).

Test 1-2: Determination of the friction force and the coefficient of static friction of the plywood plate-concrete

The friction force is the horizontal force at the base of the shoring jack that initiates slipping of the shoring jack's plywood softener plate (Figure 5). The coefficient of friction μ is then obtained by dividing the friction force by the compressive force, with:

- F: friction force = μR = μP, defined as the required force to initiate slipping of the plywood plate;
- P: compressive force in the shoring jack;
- μ: static coefficient of friction = F/P.

Three tests were carried out to determine the friction force and the coefficient of static friction of the plywood softener plate-concrete. The shoring jack was initially tightened and an increasing horizontal force was applied at the foot of the jack until it started slipping (Figure 6). The static coefficient of friction of plywood-concrete μ is calculated by dividing the maximal horizontal force F by the force P in the shoring jack.

Test 1-3: Static test on a shoring jack

The test was carried out by applying simultaneously a vertical force of 450 N and a horizontal force of 900 N by 100 N increments at a height of 1.20 m on a shoring jack installed as on site. A total of three tests was carried out as described by Test 1 of Table 1.

Test 1-4: Static test on the top rail of a section of wooden guardrail

The test was carried out by applying simultaneously a vertical force of 450 N and a horizontal force of 900 N by 100 N increments at the centre of the top rail of a section of guardrail attached to the shoring jacks as supports as illustrated in Test 2 of Table 1. The shoring jacks are installed at 1.83 m centre to centre as on sites with the prefabricated wooden guardrail of Figure 2 (c). It is tied to the shoring jacks with # 16 binding wire as shown in Figure 7.

Tests 1-5 and 1-6: Static tests on the top rail of a series of three sections of guardrails

The tests were carried out by applying simultaneously a vertical force of 450 N and a horizontal force of 900 N by 100 N increments on the top rail of a series of three sections of guardrail attached to the shoring jacks as supports as illustrated in Tests 3 and 4 of Table 1. The shoring jacks are installed at 1.83 m centre to centre as on sites. For these tests, the prefabricated wooden guardrail of Figure 2 (c) has been used. For Test 1-5, the forces are applied at the centre of the end span of the guardrail while for Test 1-6, they are applied at the centre of the central section of the guardrail. As the guardrails are 2.4 m long (8 ft.), they overlap about 600 mm (24 in.) on the shoring jack as illustrated in Figure 7.

11. RESULTS AND ANALYSIS OF STATIC TESTS IN SERIES 1

11.1. Compressive force, friction force and coefficient of friction

Table 3 gives the main results of static tests of series 1. With a 300 mm handmade key, the compressive force P generated

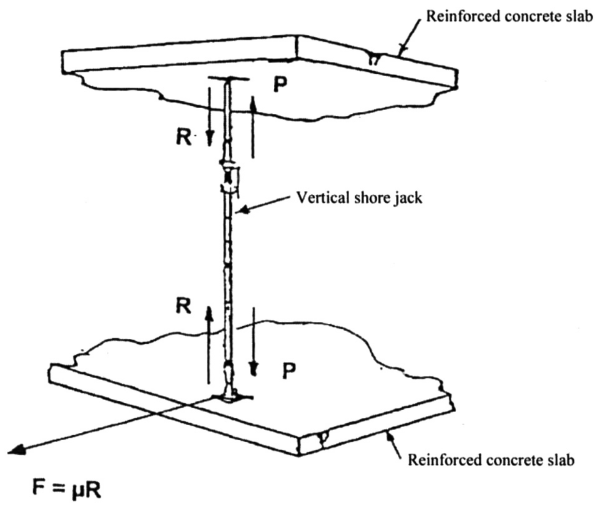


Figure 5. Friction force in a shoring jack and coefficient of static friction μ.

Figure 4. Tests 1-1a, 1-1b and 1-1c to determine the compressive force in a shoring jack.

Figure 6. Determination of the friction force and the coefficient of static friction μ.

in the shoring jack is 18 to 20 kN, whether the screw was dry or oiled. The friction force F of the shoring jack tightened between the two slabs was measured between 6.5 to 8 kN, from which a coefficient of static friction of μ = 0.44 to 0.49 was calculated.

11.2. Compliance to S-2.1, r.4

Section 3.8.2. of S-2.1, r.4 stipulates that the guardrail must resist a horizontal force of 900 N and a vertical force of 450 N applied at any point of the top rail. The maximal loads occur in the top rail when theses forces act at mid span of the top rail. The horizontal load of 900 N is supported by the two shoring jacks. The maximum loads in the shoring jack occur when the 900 N horizontal and 450 N vertical forces act directly on it. When tightened between two slabs, the shoring jacks can resist to at least 6.5 kN each before slipping. This resistance is more than seven times the applied force. The maximum displacements, about several millimetres, are mainly due to the readjustment between the inner and outer tubes of the shoring jack and to the bending of the top rail. Thus, guardrails with shoring jacks as supports, are safe and comply with S-2.1, r.4.

11.3. Shoring jacks as anchors for a travel restraint system

To verify if the shoring jack can be used as an anchor for a travel restraint system, we use the design code CSA Z259.16-09 *Design of active fall protection* (14) and the criteria of certified anchorages of ANSI/ASSE Z359-2007 Fall Protection Code (15) (16) (17). CSA Z259.16-09 stipulates that a structural member has the required strength if its factored resistance is greater than or equal to the most unfavourable factored combination of loads acting on it. This is expressed by the following equation:

$$\Phi R \geq \alpha_D D + \Psi(\alpha_A A + \alpha_L L + \alpha_Q Q + \alpha_T T)$$

where:

- ΦR: Factored resistance;
- D: dead load; A: arrest force; L: live load; Q: wind, earthquake; T: influence from temperature changes, creep or shrinkage;
- Reduction factor Φ = 0.9;
- Load factors α_D = 1.25; α_A = 1.5; α_L = 1.5; α_Q= 1.5 and α_T = 1.25;

Figure 7. Wooden guardrail attached to shoring jacks with # 16 binding wire - Overlapping of guardrails on a shoring jack.

Table 3. Results of static tests - Series 1.

Test	Maximum force	Comments
1-1a	P = 20.3 kN	Tightening with oiled screw
1-1b	P = 18.1 kN	Tightening with dry screw
1-1c	P = 18.6 kN	Tightening with lightly oiled screw
1-2a	P = 14.8 kN F = 6.5 kN	Tightening with dry screw $\mu = F/P = 0.44$
1-2b	P = 16.78 kN F = 8.3 kN	Tightening with dry screw $\mu = F/P = 0.49$
1-2c	P = 19.5 kN F = 8.8 kN	Tightening with lightly oiled screw $\mu = F/P = 0.45$
1-3	900 N horizontal 450 N vertical	• No base displacement • Displacement of 2 mm around 800 N due to adjustment of the male and female tubes of the shoring jack • Max. tightening: 9/16 turn • Dry screw (where the force is applied) • Oiled screw (base) • Vertical force applied at 41½ in. from the bottom
1-4	900 N horizontal 450 N vertical	• No slipping, no rupture • Measurement of vertical deformation at 47½ inches from the bottom • Max. tightening.: right post: ¾ turn Left post: 7/8 turn • Applied vertical force at 47½ inches from the bottom
1-5	900 N horizontal 450 N vertical	• No slipping • No deformation • Posts' tightening, from left to right # Turns Threading 1 1 1/8 Dry 2 ½ Oiled 3 1 1/8 Oiled 4 7/8 Dry • Vertical force applied at 47½ inches from the bottom
1-6	900 N horizontal 450 N vertical	• No slipping • No deformation • Posts' tightening, from left to right # Turns Threading 1 7/8 Oiled 2 5/8 Dry 3 ¾ Dry 4 7/8 Oiled

Ψ: load combination factor as follows:

- $\Psi = 1$, where only A is applied
- $\Psi = 0.7$, if A acts in combination with either L or Q
- $\Psi = 0.6$, if A acts in combination with both L or Q

Clause 7.2.2 (b) of CSA Z259.16-09 stipulates that temporary restraint anchorage shall be designed using static analysis with A = 1.8 kN. The factored arrest load on the anchor is $\alpha_A A = 1.5 \times 1.8$ kN = 2.70 kN. The friction forces measured in tests 1.1a, 1.1b and 1.1c vary from 6.5 to 8.8 kN. The minimum factored resistance of the shoring jack is $0.9 \times 6.5 = 5.85$ kN. Thus with $\Phi R = 5.85$ kN $\geq \alpha_A A = 2.70$ kN, the shoring jack has the required resistance as an anchor for a travel restraint system for not more than 2 workers.

Clause 5.4.4.1 of ANSI/ASSE Z359.2-2007 Minimum Requirements for a Comprehensive Managed Fall Protection Program (16) stipulates:

Anchorages selected for restraint and travel restraint systems shall have strength capable of sustaining static loads applied in the directions permitted by the system of at least:

A) 1,000 pounds (4.5 kN) for non-certified anchorages, or
B) Two times the foreseeable force for certified anchorages.

The friction forces measured in tests 1.1a, 1.1b and 1.1c vary from 6.5 to 8.8 kN. Based on these results, the shoring jack has the required resistance as an anchor for a travel restraint system according to CSA Z259.16-09 and ANSI/ASSE Z359.2. The travel restrain system concept is excellent. It prevents the user from getting in the fall hazard area and thus from falling. However, in practice, travel restraint systems are not foolproof because the length of the lifeline is not always properly adjusted or the self-retracting lifeline may be longer than the distance to the nearest edge and in case of an accidental fall, may lead to a fatality as the anchor points have not been designed to arrest an accidental fall. Moreover, its implementation on site is very difficult and often leads to misuse and subsequently to fatality (18). Consequently, the shoring jack must not be used as an anchor for a travel restraint system.

12. DYNAMIC TESTS – RESULTS OF SERIES 2

All dynamic tests were carried out as described in Table 2. Table 4 gives the summary of dynamic tests results. For test 2-1, the shoring jack didn't move. It can withstand a horizontal load of about 6.5 to 8.8 kN (see tests 1-2). For tests 2-2, 2-3 and 2-4, the top rail is higher than the centre of gravity of the 100 kg wooden torso, thus, it didn't topple over the top rail. No displacement of the shoring jacks occurred.

13. CONCLUSIONS

13.1. Tightening test

The results of tightening tests (Tests 1-la, 1-lb et 1-lc) from Table 3 show that the compressive force that a worker can generate in a shoring jack tightened between two concrete slabs with a handmade tool is 18 to 20 kN, whether the screw of the shoring jack was dry or oiled. The friction force of a shoring jack tightened between two slabs was measured between 6.5 and 8.8 kN, which gave a coefficient of static friction of plywood-concrete of μ = 0.44 to 0.49.

13.2. Compliance with the Quebec Safety Code for the Construction Industry S-2.1, r.4 – Static tests

The overall displacements with respect to the applied forces in the direction of the horizontal and vertical loads are small. The greatest displacements occurred in the horizontal direction and are mostly due to the adjustment between the two tubes of the shoring jack and to the bending of the top rail. The guardrail must resist to a horizontal load of 900 N and a vertical load of 450 N applied at any point of the top rail. The maximal loads on the top rail are obtained when these loads are applied at midspan of the top rail. The wooden frame of 40 × 90 mm (2 × 4) easily supports the 450 N vertical load. The horizontal 900 N load is supported by two shoring jacks which can resist to at least 6.5 kN each before slipping. This resistance of the shoring jack is about 15 times greater that the applied force. When the loads are applied directly on the shoring jack, it has to support 900 N horizontal. The shoring jack can resist to 6.5 kN before slipping. This resistance is about 7.7 times the applied loads. Thus, guardrails built on site with shoring jacks as supports, are safe and comply with S-2.1, r.4.

13.3. Dynamic tests

In test 2-1, the shoring jack did not move. We can conclude that the impact force of the 100 kg wooden torso on the shoring jack is less than 6.5 kN (see Test 1-2). In Tests 2-2, 2-3 et 2-4, the top rail was higher than the centre of gravity of the 100 kg wooden torso which did not topple over and the shoring jacks did not move. The shoring jacks as supports succeeded the dynamic tests.

13.4. Use of shoring jacks as supports

As stated by IHSA, the shoring jack is a strong support which has proved itself in the construction industry in North-America. The wooden or metallic frames used as guardrails must meet the resistance requirements specified by construction codes. In fact, these frames governed the resistance of the guardrails. The tightening force of the shoring jacks have to be verified periodically because vibration, creep, shrinkage and concrete deformation may loosen the shoring jacks and put them out of plumb. Consequently, guardrails with shoring jacks as supports are safe and comply with the Quebec safety code for the construction industry. The tightening force of a worker with a handmade manual tool can generate a high compression force in the shoring jack and a friction force about ten times greater that the strength requirement of the Quebec safety code for a guardrail. During the construction of the reinforced concrete structure, apart from creep and shrinkage of concrete, there is generally no temporary or permanent installation that generates vibration which can loosen the shoring jacks. The vibration could come during the placing and vibrating of concrete during the construction of the upper floors, but this is not damageable for the loosening of the shoring jacks. However, it is advisable for workers to

Table 4. Tests results of series 2.

Test	Maximum load	Comments
2-1	The jack didn't move	Post's tightening from left to right Post – Turns – Threading 1 – ½ – dry 2 – ¾ – oiled
2-2	The 100 kg wooden torso did not topple over the top rail	• Rupture of the top rail (dry wood) • Verification of tightening = no loss • Post tightening from left to right Post – Turns – Threading 1 – 5/8 – dry 2 – 7/8 – oiled lightly
2-3	The 100 kg wooden torso did not topple over the top rail	• No rupture • Very slight loss of tightening on posts 2-3-4 not measurable • Post tightening from left to right Post – Turns – Threading 1 – 7/8 – oiled lightly 2 – 5/8 – dry 3 – 1 – dry 4 – 1 – oiled lightly
2-4	The 100 kg wooden torso did not topple over the top rail	• Rupture of rollers and of manikin • Post tightening from left to right Post – Turns – Threading 1 – 7/8 – oiled lightly 2 – 5/8 – dry 3 – 1 – dry 4 – 1 – oiled lightly

watch for any loosening of any components of the formwork such as nut-washers and wedges during vibration.

13.5. Recommendations

Based on laboratory results, here are the main recommendations of the study.

(i) Guardrails with shoring jacks as supports are reliable and they comply with the requirements of the Quebec safety code for the construction industry. They can be used safely as supports for guardrails on construction sites.
(ii) The dynamic tests with the 100-kg (220-lb.) wooden torso are very severe tests and do not reflect the reality of an impact of a worker on the top rail of the guardrail. Further research is required to design a more realistic test to simulate the arrest of a worker by a guardrail.
(iii) The shoring jack used as supports for guardrail must not be used as an anchor for a travel restraint system.

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REFERENCES

(1) CRSI. (2007). *Structures: The Sum of Their Parts*. Concrete Reinforcing Steel Institute. http://www.vcrsi.org/index.cfm/engineering/about
(2) ACI Committee 347-04. (2011). *Formwork for concrete*. Detroit, Michigan: Ed. M. K. Hurd.
(3) S-2.1, r.4. (2011). Code de sécurité pour les travaux de construction du Québec. *Les Publications du Québec*. Québec: Gouvernement du Québec.
(4) RSST. (2012). *Règlement sur la santé et la sécurité du travail*. Québec: Éditeur officiel du Québec.
(5) OSHA. (2012). *Part 1926 Subpart M CFR 1926.500 - Fall Protection for the Construction Industry*. Washington, D.C.: U.S. Department of Labor.
(6) Lan, A, Arteau, J, Daigle, R. (2005). Développement et validation d'une méthode d'évaluation des garde-corps fabriqués et installés à pied d'œuvre sur les chantiers. Rapport de recherché. Montréal: IRSST.
(7) IHSA. (2012). *Guardrails*. Toronto, Ontario: Infrastructure Health & Safety Association.
(8) Lan, A., Daigle, R. (2009). Development and validation of a method for evaluating temporary guardrails built and installed on construction sites. *Safety Science*, 47(2): 215-226, doi: http://dx.doi.org/10.1016/j.ssci.2008.03.001.
(9) Jacmin, M., Mayer, A. (1984). Écran garde-corps - Protection contre les chutes de grande hauteur pour les travaux d'étanchéité en toiture. *Travail et Sécurité*.
(10) Bobick, T, McKenzie, T. (2011). *Guardrails - Development of a multifunctional system. ProfessionalSafety*. Illinois, USA : ASSE.
(11) ST03-19. (2003). *Report ST03-19. Static and dynamic tests on different types of guardrails*. Montréal: Department of civil engineering - École Polytechnique de Montréal.
(12) CSA. (2010). *CSA-A23.3-10, Design of concrete structures*. Canadian Standards Association.
(13) CSA. (2009). *CAN/CSA-086-09, Engineering Design in Wood - Limit States Design*. Canadian Standards Association.
(14) CSA. (2009). *CSA Z259.16-09 Design of active fall protection*. Canadian Standards Association.
(15) ANSI. (2007). *ANSI/ASSE Z359.1-2007, Safety Requirements for Personal Fall Arrest Systems, Subsystems and Components*. American National Standards Institute.
(16) ANSI. (2007). *ANSI/ASSE Z359.2-2007, Minimum Requirements for a Comprehensive Managed Fall Protection Program*. American National Standards Institute.
(17) ANSI. (2007). *ANSI/ASSE Z359.3-2007, Safety Requirements for Positioning and Travel Restraint Systems*. American National Standards Institute.
(18) Sulowski, A.C. (2003). *Comments on the CAN/CSA Z259.16-04 draft to the CSA Z259 technical committee on fall protection*. Toronto, Ontario.

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