STABILITY ANALYSIS ON DIFFERENT TYPE OF STEEL SCAFFOLDS

AUTHOR: PAU GUILLAMÓN CAUSI
DIRECTOR: GIAN-PAOLO CIMELLARO
ACADEMIC YEAR: 2012-2013
STABILITY ANALYSIS ON DIFFERENT TYPE OF STEEL SCAFFOLDS

Cimellaro, Gian Paolo\textsuperscript{1}, Erbeta, Maurizio\textsuperscript{2}, De Stefano, Alessandro\textsuperscript{3}

ABSTRACT

During the lifetime of a building, the highest risk is in the construction phase. The collapse of scaffolding systems occurs quite often with considerable accidents reported. This paper studies the major flaws or imperfections sequences that lead more easily to the collapse of a scaffolding system. The study has been focused in three different types of steel scaffolding systems: joint tubes, multidirectional and prefabricated systems, which are the most commonly used in construction. Diverse load tests on these different types of steel scaffolding systems have been made with commercially available software. The analysis has considered building imperfections, diverse base boundary conditions, effects of lateral restraint arrangement and different load distributions. Finally, the study propose an empirical formula to determine the critical load of a steel scaffolding system using the typology of the scaffolding system, the number of story levels and the different boundary conditions.

KEYWORDS: collapse, construction, structural analysis, steel scaffolds, scaffold support system

1. INTRODUCTION

Almost every construction operation in every part of the world utilizes scaffolding systems in order to support men, materials and structural elements. The collapse of scaffolds not only leads to work delays

\textsuperscript{1} Assistant Professor, Department of Structural & Geotechnical Engineering (DISTR), Politecnico di Torino, 10129 Torino, Italy, E-mail: gianpaolo.cimellaro@polito.it

\textsuperscript{2} Clifford C Furnas Eminent Professor, Department of Civil, Structural and Environmental Engineering, University at Buffalo (SUNY), 135 Ketter Hall, Buffalo NY 14260 E-mail: reinhorn@buffalo.edu

\textsuperscript{3} Professor, Department of Civil, Structural and Environmental Engineering, University at Buffalo (SUNY), 130 Ketter Hall, Buffalo NY 14260 E-mail: bruneau@buffalo.edu
and property loss, but has also been responsible for numerous worker injuries and deaths (see Figure 1). The recent scaffolding collapses in a coal power plant in Barangay Malayaat, Pililia, Rizal, in an art workshop in Xianrendong village, Changping district in northern Beijing and at Putney, in south-west London, demonstrate the potentially fatal consequences of overloading scaffolding systems. With such a tremendous investment in the form of lives and property resting on the scaffolding system, it is imperative for all involved to know with a high degree of certainty the load carrying capacity.

![Figure 1 Injured distribution according to the construction sector](image)

1.1 Literature review

The studies on the provisional scaffolding made by Chan et al. [1] developed the analysis of prefabricated steel frame scaffolding uniformly loaded, there are no consideration of any eccentricity load. An advantage of this analysis is the fact that there have been considered different degrees of connection stiffness by the concept of effective length: pin, semirigid and rigid joints.

The studies made by Peng et al. [2][3] analyzed the combination of modular steel scaffolds and wooden shores, used for temporary support during the construction of high-clearance concrete buildings.
A nonlinear analysis for a three-story scaffolding system was made with a 9% difference between the analytical and the experimental results. The finite element analysis has been performed considering only the structure of the scaffolding and of the shores. It has not been considered the contribution of the deck, neither the plan stiffness, to be in favor of safety. These two aspects are analyzed in this paper to achieve more faithful results to the real structure of the scaffoldings.

Experimental load tests of steel frame scaffolding systems have been carried by Weesner et al. [4], the results of these experimental tests have been verified with a commercial software for the analysis of framed structures. These studies have been very useful as they have been able to compare the theoretical analysis with experimental results. They studied the load carrying capacity of three-storey scaffolds assuming rigid joints between stories, and pin joints for the top and the bottom boundary conditions. The results of their elastic buckling analysis came out to be rather larger than the test values with the percentage differences ranging from 6% to 17%.

A similar study was carried by Yu et al. [5][6] and Chung et al. [7] to analyze the behavior of multi-storey prefabricated scaffolding. The innovation of this study is that the finite element analysis has been done considering different types of connection between floors. The loads are applied to the structure without considering any eccentricity in both analyses. Furthermore, it is estimated that the absence or improper installation of the cross-bracings will affect significantly to the load carrying capacities of the scaffolds. This paper takes into account these improper installations by removing cross-bracings in different analysis.

Additional experimental tests were certainly performed by Peng et al. [8]. Object of these tests is the door-shaped steel scaffold: for simulating lateral unrestrained condition of the top layer boundary of the scaffold during the test, the scaffolding system was placed upside down. The bottom part of the upside down scaffolding structure is the top part of the original scaffolding structure and it rests on steel plates that ensure an unrestrained movable condition of the scaffolding system. A centric load and three
eccentric loads were studied in the tests, some cross-braces were also removed to analyze how varies the behavior of the critical load.

In the numerical analysis described before, there are performed elastic analyzes of second order, which take account of the geometric nonlinearity i.e. the stress arise as a result of the significant deformation of the structure, the curve has at its upper limit the elastic critical load $P_{cr}$.

The purpose of this research is to analyze the behavior of steel scaffolding focusing on safety concerns that may arise on site. To investigate the causes of the collapse of steel scaffolding, three different models have been developed. The major flaws or imperfections sequences that lead more easily to the collapse of the scaffolding have been studied in this work. Finally, this paper proposes an empirical formula to determine the critical load of a scaffold using the type of scaffolding system, the number of floors and the different boundary conditions.

2. STEEL SCAFFOLDING - TYPOLOGIES OF CONSTRUCTION

2.1 Typologies of steel scaffolding

This section focuses on the most commonly used types of steel scaffolding. The aim is to evaluate the critical loads or any special condition that may lead to the collapse of the scaffolding systems and then endanger the health of workers.

Scaffolding, in fact, are provisional reticular structures multistory that, given their slenderness, entails risks of sudden collapse, which happens to the achievement of the critical load without any manifestation of phenomena of deformation.

In the construction sector there are different types of systems that allow the operator to work at elevations higher than the surrounding land, among them we have scaffoldings.
Scaffoldings, until the early twentieth century, were made of wood (the most famous scaffolding remember the one made by Michelangelo for the construction of the dome of St. Peter's Basilica in the Vatican), while modern ones are almost all made of steel and sometimes aluminum. In Asian countries are also used bamboo structures.

Steel scaffoldings can belong to one of the following three systems:

- Joint tubes system: Better known as scaffolding of pipes *Innocenti* (so called after the inventor Ferdinando Innocenti), very versatile and suitable for any type of use, but needs more work to be mounted.
- Multidirectional system: Enough flexible and generally suitable for the realization of three-dimensional structures.
- Prefabricated system: Designed for use on façades of linear buildings.

2.1.1 *Steel scaffoldings with joint tubes*

This typology allows working at considerable heights, thanks to the creation of stacked decks, through the connection of steel pipes vertically and horizontally, obtained with the aid of special joints preprinted. It is in essence a "spider web" of uprights, cross-members and diagonal bracing, suitably bound to each other and anchored to the building, with the aim to create work surfaces to required heights. The typology of scaffolding on tubes and joints is still widely used because it is extremely flexible; it facilitates the creation of work plans on complex façades, articulated, curved or with changes of considerable magnitude, due to the many dimensions of the modules with which are made the tubes (see Figure 2).

This type is also extremely common in the maintenance and restoration of large historical and monumental complexes, and has spread recently to the construction of canopies, shelters, barriers and structures for advertising, trade shows, sporting events, etc. (see Figure ).
The main problems of scaffolding with joint tubes are made up from the more or less correct installation of the elements (see Figure 2). It's, in fact, extremely important to pay attention to the junction of the tubes, so that the verticality and / or the inclination envisaged will be maintained to the
anchorages and to the supports on the ground. For these reasons it would be advisable (though is not always the case) delegate the installation of this equipment to qualified, capable and knowledgeable personnel, properly trained and informed of the risks and dangers that this activity causes.

Figure 4 Structural detail of the joint tube scaffold

2.1.2 Multidirectional scaffold

These scaffolds of last generation are still little used. They are sold only in scaffolding galvanized and can be used to accomplish the most complex and convoluted work; in classical structures, in construction and in building maintenance (see Figure 3).

Figure 3 (a) Multidirectional scaffolds (b) geometry of a single element (mm)
Unfortunately, the cost still very high and because of the lack of disclosure on the Italian market for this type of scaffolding, it is difficult to see mounted (while in Europe it is widespread). In Rome, the Vatican has been restored with the multidirectional scaffolding and proved to be the only type of scaffold suitable to bind the walls that have an infinite number of projections, indents, columns and other situations of the utmost delicacy.

The handling of components and ease of mounting allows very high productivity and adaptability to any problem with the site.

Fast and flexible in use, easy to assemble, combines the productivity of the typical prefabricated scaffolding with the flexibility and universality of the scaffolding with joint tubes. The modularity allows a large number of combinations.

In all cases, even for the multidirectional scaffolding it's applied the same rules of scaffolding fixed. The elements that constitute multidirectional scaffoldings are a series of rods to which are fixed the crowns perforated, allowing the performance on multiple directions of the scaffolding. Horizontal irons, with variable lengths, define the distance between the various drawn up of scaffolding (see Figure 4). The mounting of this type of scaffolding must be such as that described by fix scaffoldings.
2.1.3 Prefabricated scaffold

Steel and prefabricated scaffoldings are now the most common type and the most used in construction industry, and for this reason are also those in which the manufacturers pay more attention, they are always looking for technical improvements to reduce costs, increase performance and reliability, contracting the time of installation and subsequent disassembly. In fact, scaffolding systems realized with prefabricated frames are made by assembling a few pieces (real frame, current, railings, decking planks, toe boards, diagonal stiffening, sideburns, valances) designed and manufactured to facilitate and make repetitive operations of assembly, so as to enable the installation of the structure in a short time, even to not highly qualified personnel.

![Figure 5 Prefabricated scaffold (b) geometry of a single element (mm)](image)

With regard to the peculiar characteristics of this type of temporary works, it must be remembered that each company produces at least a pair of models of prefabricated scaffoldings, which differ among themselves for the width of the worktops (generally 70 cm or 105 cm transversely between the center distances of the two uprights), for the amplitude of the bays (180 cm, 250 cm and 300 cm...
longitudinally) and for the shape of the base frame (for H or portal); while the height is fixed (equal to 200 cm). In addition, prefabricated scaffolds may differ for the method of fastening between the frames itself and the current or the stiffeners (as pins or as bushings) (see Figure 5).

Of course the choice of which model adopted is left to companies that rent or purchase the equipment, according to specific needs and types of work.

2.2 FEM Model

The analysis of the different types of scaffolding systems has been made using the commercial finite element software SAP2000 v14 [9][10]. The numerical model must take in consideration the real characteristics of the different scaffolds. It is necessary to define the geometry, the material properties, the loads considered and the different boundary conditions. Like other such software, SAP2000 v14 offers both classic buckling analysis and a pushover prediction of ultimate capacity. Each frame was analyzed using both modes of analysis.

2.2.1 One story level model

2.2.1.1 Geometry

The model used in the analysis must, first, be consistent with the real elements marketed in the construction industry.

The configuration of the module reference constructive multi directional realized for numerical analysis provides for the arrangement of 4 uprights, arranged to create a parallelepiped with a length of 1.8 m, width 1.14 m and a height of 2 m. Below the uprights are arranged the elements of departure (see Figure 6). The uprights are connected at the top by 4 stringers (two on the short side and two on the long side).
The SAP2000 software divides the frame elements in 5 nodes as default. This option can be changed to increase the accuracy of the results but this change increase the analysis time too. The Shell elements have been changed into elements with a mesh 8X16, consisting of quadrilateral elements.

Figure 6 SAP structural model of a single scaffold with joint tubes

### 2.2.1.2 Materials

All elements used in the model are made up of steel S235JR. The mechanical properties of the steel are defined in Figure 7.

<table>
<thead>
<tr>
<th>MATERIAL PROPERTIES:</th>
<th>STEEL S235JR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus $E$</td>
<td>200000 $N/mm^2$</td>
</tr>
<tr>
<td>Poisson’s coefficient $v$</td>
<td>0.3</td>
</tr>
<tr>
<td>Yield stress $f_y$</td>
<td>235 $N/mm^2$</td>
</tr>
<tr>
<td>Tensile strength $f_u$</td>
<td>360 $N/mm^2$</td>
</tr>
<tr>
<td>Weight per unit volume</td>
<td>76972.86 $N/m^3$</td>
</tr>
</tbody>
</table>

Figure 7 Material properties of steel for the multidirectional model

### 2.2.1.3 Boundary conditions

The critical points of the modeling are related to the degrees of constraint that take place between the elements and between the element and the outside world. Internal constraints, which are the connection point between the tubes of the scaffolding, are modeled as joints.
2.2.1.3.1 Base boundary conditions

The tradition of building scaffolding and temporary structures expected to be placed, at the base of the structure, sideburns. These normally rest on wooden planks or on plates of concrete (see Figure 8).

![Figure 8 Structural detail of the hinge beam at the base for multidirectional scaffold](image)

The definition of the base constraint is therefore considerably complex. The adoption of the support coupling with horizontal scrolling is too conservative and incorrect since the load due to its own weight does not allow the structure to move on the horizontal plane. The constraint of fixed the base could be assumed, but it is not guaranteed the moment of fixed the base. The solution of hinge base is the only one consistent with the real situation of the structure on site. The analysis considers two cases: hinge and fixed base.

2.2.1.3.2 Lateral support

The lateral supports are a particular boundary condition thanks to which the structure of the scaffolding is fixed to the vertical structure of maintenance or construction. In the model under consideration the lateral support is provided only for multi storey models, on the top story level of the two external vertices. To simulate this constraint has been modeled a frame element with the properties of the scaffold tube and a length of 20 cm. One end is fixed to the scaffolding with constraint of an internal hinge while the other prevents the orthogonal movement to the vertical plane of the building. The
modeled tube is grafted to each vertical upright at a distance of 10 cm from the surface of the plank (see Figure 9).

![Diagram](image)

Figure 9 (a) Structural detail of the lateral support (b) SAP model

2.2.1.4 Load distribution

The objective of the analysis is to determine the critical load of the frame. Both for the analysis of buckling and for that of pushover was used a unit load (1 Newton) obtaining as a result the critical load as a multiplier of the initial load.

In many real cases, the loads are applied in generic positions of the structure. It is, therefore, necessary to study the effect of the eccentricity of the load on the critical load. The procedure used provides nine different configurations of load or loading positions. The centered position is the position
number 1 and provides that the load is centered in both directions. The other positions are represented in

![Figure 10](image1.png)

Figure 10. Plan view of the different axial load distributions considered in the analysis

2.2.2 Multi story model

The analysis has been made for different dispositions of the frames. For the three types of scaffolds the one story-level initial model is used as a basic module. The starting module has been used to realize configurations up to the case of a 15-storey structure with single span (see Figure 11), but also to
simulate a structure of a one story-level with two and with three bays. We proceeded in a similar way with a three-storey and three bays (see Figure 12).

![Figure 11 SAP model of (a)1 story, (b) 2 story, (c) 3 story single bay, prefabricated scaffold frame](image)

2.3 Imperfections

The hypothesis on the geometry and the configuration adopted previously assumed that the structure is perfectly installed and implemented. In fact, lack of specialization of certain operators and restricted time available may change some aspects of structural configurations. For example one or more diagonal
bracing can be the forgotten of installation. Other situations can be created from incorrect procedures for the attachment of the coupling elements, changing the degree of internal constraint between the elements.

The imperfections are not only due to negligence of the operator but may be of a different nature. Imperfections during the manufacture, such as not perfect straightness of the elements, imprinted curvatures, states of internal residual stresses, local reduction of the thickness of the tubes.

2.3.1 **Building imperfections**

Each configuration of load is applied on different models, in which they were removed bracing elements. The removal of the diagonal elements follows a rule common to all analyzes. The 7 different structural configurations are represented in Figure 13.

![Figure 13 Scenario events considered in the analysis](image)

2.3.2 **Manufacturing imperfections**

During the industrial process, some elements can have different characteristics from those described theoretically in catalogs and data sheets. It happens that the real elements, leaving the factory manufacturer, have several imperfections that may affect the structural behavior.
The main imperfections founded are the non straightness of the axis, the variations of sections, the presence of cracks or fissures and elements with a state of residual tension.

3. ANALYSIS RESULTS

The comparison between buckling and plastic load function of the normalized distance for one story and one bay model with fixed and hinge base is shown in Figure 14. The analysis shows that in the case of hinge base the plastic load is bigger than the buckling load. The buckling load remains stable in 100 kN for any normalized distance so it can be considered as the critical load. In the fixed base case the values remain steady between 200 and 400 kN.

Figure 14 Comparison between buckling and plastic load vs. function of the normalized distance: 1 story 1 bay model with (a) fixed and (b) hinge base

In Figure 15 is shown the comparison between the boundary conditions for the three scaffold typologies studied. In the three cases, the analysis shows that the fixed base holds more load than the hinge base. For multidirectional scaffold the fixed base holds two times more than hinge base and in the prefabricated scaffold case this relation increases in four.
The comparison between the boundary conditions for the three scaffold typologies for different story levels with centralized load is shown in Figure 16. In the joint tubes scaffold the presence or not of the lateral support and the different boundary conditions are not very influential. The behavior of the scaffold remains constant around 300 kN, from the fourth story level for all the cases. The multidirectional scaffold presents some differences in his behavior; in this case the presence of fixed or hinge base is the most influent boundary condition and the presence of the lateral support improves a little the behavior of the structure, the buckling load increases from 300 to 350 kN and from 600 to 650 kN for hinge and fixed base respectively. Apparently there is not a considerably influence of the number of story levels. Finally in the prefabricated scaffold case, the lateral support boundary condition does not seem to influence significantly the hinge base configuration. In fact from the third story level the buckling load remains steady between 100 and 200 kN. For the fix base instead the lateral support increases the buckling load when the number of stories increases.
The study of different load dispositions is made for the three scaffold typologies for different story levels and different boundary conditions (Figure 17). The joint tubes scaffold shows that the eccentricity is important for the first’s story levels. In the cases without eccentricity, for the fixed base case the buckling load is 50% higher than the hinge base for the first floor and decreases linearly, after the fourth floor the boundary conditions at the base don’t have any influence, the buckling load remains constant at 300 kN. In the cases with eccentricity the behavior is the same but the change comes after the second floor and the value remains steady at 100 kN. The multidirectional scaffold behaves more instable than the joint tubes scaffold. The eccentric load decreases the buckling load considerably; six times for the fixed base and 3 times for the hinge base. Apparently the number of story levels doesn’t influence on the behavior. In the prefabricated scaffold, two behaviors are observed; for the hinge base the buckling load remains constant around 100 kN while for the fixed base the buckling load decreases constantly from 400 and 300 to 125 and 150 without and with eccentric load respectively. In both base conditions the eccentric load decreases approximately a 20% the buckling load.
Figure 17 Effect of the boundary conditions at the base and of the eccentric load vs. the number of stories

The effect of different cases of building imperfections can be observed in Figure 18. The joint tubes scaffold shows two different behaviors; for the four firsts cases the buckling load decrease from 300 to 100 kN for centric an eccentric load respectively, for the rest of cases the buckling load is constant for every normalized distance. The multidirectional scaffold behaves as the joint tubes scaffold, the buckling load decreases for the three first cases from 250-300 to 100 kN, for the other cases the buckling load remain stable. For the prefabricated load only four cases are possible and in all of these cases the buckling load remains steady in values between 50 and 110 kN.
Finally, Figure 19 shows the comparison between the three types of scaffolds according to the eccentric load function of the number of story levels. For the hinge base without eccentric load the behavior between the joint tubes and the multidirectional scaffold is the same, while the prefabricated scaffold presents a lower buckling load. The presence of an eccentric load decreases this difference making a very similar behavior between all types of scaffolds. The presence of a lateral support makes a similar behavior between the joint tubes and the prefabricated scaffold for the first story level, the buckling load decreases when the number of story levels rose and the behavior between the three types
of scaffold become very close after eight story levels. The hinge base with lateral support improves the behavior for eccentric load for the first story levels but in comparison with the centric load the buckling load decreases considerably.

Figure 19 Comparison between the three types of scaffolding systems according to the eccentric load function of the number of story levels.
3.1 Proposed formula

The interpretation of the results obtained for the different types of scaffolds allows proposing an empirical formula enabling to determine the critical load of a scaffold considering different parameters.

\[
P_{\text{critical, normalized}} = \frac{P_{\text{critical}}}{W_{\text{structure}}} = \frac{A}{\phi_{\text{ecc}}} \cdot \alpha^{\eta_{\text{ecc}}} \tag{1}
\]

Where \(W_{\text{structure}}\) is the total weight of the structure considered, \(A\) is the flow factor, defined as a function of the type of scaffold, \(\phi_{\text{ecc}}\) is the reduction factor for eccentricity (defined by change in position of the load), \(n\) is the number of story levels, \(\alpha\) is the flow coefficient, defined according to the type of scaffold and \(\eta_{\text{ecc}}\) is the correction of efficiency for eccentric loads. All this parameters can be founded in Figure 20.

This formula has been the best possible approximation. In fact, for all types of curve analyzed, the value \(R^2\) (determination coefficient) has been higher than 0.997 for the hinge base case and higher than 0.958 for the hinge base and lateral support case.

<table>
<thead>
<tr>
<th>Typology</th>
<th>(A)</th>
<th>(\phi_{\text{ecc}})</th>
<th>(\alpha)</th>
<th>(\eta_{\text{ecc}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>112</td>
<td>1,460</td>
<td>0,99</td>
<td>0,01</td>
</tr>
<tr>
<td>JT</td>
<td>245,4</td>
<td>2,879</td>
<td>1,03</td>
<td>-0,1</td>
</tr>
<tr>
<td>MD</td>
<td>247,2</td>
<td>2,737</td>
<td>0,98</td>
<td>-0,01</td>
</tr>
</tbody>
</table>

Figure 20 Experimental parameters for the formula.

The eccentricity effect has been only considered for the conditions of extreme load (centric and eccentric load). Possible developments of this formula may incise in the investigation of other intermediate states of eccentricity.
Another important aspect is related to the scaffolding imperfections which can be considered as scaffolding configurations. It is possible that the building situation oblige to build scaffolds without certain elements. This aspect can be considered in the definition of two other parameters in the formula.

\[
P_{\text{critical, normalized, case } i} = P_{\text{critical, normalized, reference case }} \cdot \eta_c \cdot \eta_d = \frac{P_{\text{critical}}} {W_{\text{structure}}} = \frac{A} {\varphi_{\text{ecc}}} \cdot \eta^{c} + \eta_{\text{ecc}} \cdot \eta_{c} \cdot \eta_{d}
\]  

(2)

Where \(P_{\text{critical, normalized, reference case}}\) is the critical load in the normalized case obtained for the complete configuration, \(\eta_{c}\) is the efficiency coefficient for the structural configuration (see Figure 21) and \(\eta_{d}\) is the reduction factor for the state of degradation of the elements (see Figure 22).

The efficiency coefficient \(\eta_{c}\) has been defined only for the centric load case. The eccentric load case can be studied in future.

<table>
<thead>
<tr>
<th>Case</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient (\eta_{c})</td>
<td>0.984</td>
<td>0.817</td>
<td>0.159</td>
<td>0.155</td>
<td>0.150</td>
<td>0.148</td>
</tr>
</tbody>
</table>

Figure 21 Efficiency coefficient for the structural configuration \(\eta_{c}\). Only for centric liad and hinge base

Figure 22 Reduction factor for the state of degradation of the elements \(\eta_{d}\).
4. CONCLUSION

This paper searches to understand what factors have more influence in the structural behavior of different types of scaffold systems.

The presence of multi story-levels does not strongly reduce the critical load. The critical load suffers, however, drastic decreases if its eccentricity is increased. The choice of the degree of external constraint can strongly influence the response of the structure. From the study it is apparent that the base boundary condition more consistent with the reality is the hinge base.

The presence of building imperfections results in a decrease of the critical load. This decrease is significant if the number of vertical elements removed is greater than two.

The comparison between the different types of scaffolds has shown a similar behavior between joint tubes and multidirectional scaffolds, due to the similar geometry. The prefabricated scaffolding system presents different results because of differences in the structural design and size.

This study has managed to define an empiric formula that predicts the critical load of a generic structure of scaffolding.

5. Acknowledgements

The research leading to these results has also received funding from the European Community’s Seventh Framework Programme - Marie Curie International Reintegration Actions - FP7/2007-2013 under the Grant Agreement n° PIRG06-GA-2009-256316 of the project ICRED - Integrated European Disaster Community Resilience.
REFERENCES