



DESIGN REVISIONS OF COMPLEX BUILDING STRUCTURES: WORK EXPERIENCE IN LITHUANIA, LEGISLATIVE, ORGANIZATIONAL AND TECHNICAL ASPECTS

Michail SAMOFALOV^a, Vytautas PAPINIGIS^b, Virmantas JUOCEVIČIUS^c

^aKlaipėda University, Department of Marine Engineering, Bijūnų str. 17, 91225 Klaipėda, Lithuania

^bVilnius Gediminas Technical University, Department of Reinforced Concrete and Masonry Structures,
Saulėtekio al. 11, 10223 Vilnius, Lithuania

^cJSC “ASD project”, Department of Structures, Molėtų pl. 47F-IIa, 08409 Vilnius, Lithuania

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Abstract. This paper presents an engineering survey based on experience of the authors during design and expertise of complex building structures in period of 2000–2014. Legal, organizational and technical aspects in a procedure of changes in structural design documentation are investigated. Separate actions for implementing changes according to legislative documents in Lithuania in technical and working structural projects are presented by a general algorithm. Actual questions about sequence in proceeding with local and global analytical calculations during designing of complex structures and peculiarities of processing revised structural drawings and text documents are described in this paper. Relevance of the subject is illustrated by an example of a successful decision in solving common construction and design problems of an office building in Vilnius. Finally, conclusions and recommendations are given. This paper is an investigation of the considered problem and is designated for science researchers in civil engineering, educational and public organizations working with refinement of the design procedures and project documentation handling, and for practicing engineers.

Keywords: building project, bearing structures, design revision, structural analysis, design work example, project documentation management.

Introduction

Design changes in a project of a complex building structure are quite a frequent phenomenon. This is the case as large investment projects are long-term procedures and are highly subjected to changes in economic environment and legislative basis (Gudienė *et al.* 2014).

It is very important to understand properly what kind of ‘an essential design change’ stands for. According to valid legislative documents in Lithuania (Lietuvos respublikos... 1996; and others) the essential design change is any change in one of key design decisions in a local project:

- replacement of bearing structures;
- changes in layout of bearing structures;
- changes in external dimensions of a building.

All other changes in project documentation are classified as trivial corrections.

Causes of demand in a project change can be either objective or subjective, for example:

- changes of a construction site;
- changes in a number of floors;
- another design manager;
- the client changes;
- an irrational technical task;
- changes in territorial planning laws;

- equipment modernization;
- confinements in the investment program etc.

It is extremely important to realize the seriousness of changes in already designed and complexly coordinated design decisions before diving into that process (Lin 2014; Öney-Yazici, Dulaimi 2014; Wang, Adeli 2014). Often, there is a wrong impression that a simpler way is to release a project revision of a complex structure than to develop a new structural project completely from scratch. A fundamental feature of essential project changes is that it requires more careful work and higher technical and organizational qualification of an engineer.

The survey, presented in this article, is illustrated by an example of an office building, built in Vilnius (Fig. 1). This building has experienced some changes during the structural design process because of evaluations in the construction process. The building has an underground parking (2 levels) and 8 storeys of a superstructure. A total area in the building is about 16 thous. sq. m.



Fig. 1. An original office building, Vilnius

During engineering practice the essential changes in projects are implemented under nonconforming conditions to the general rules of design process, insufficient financial funding for design works, when there is a non-updated old working schedule, alongside with invariable routine projects and so on. Practice of judicial and insurance expertise shows, that structures under near-to-failure condition or structural collapses due to mistakes in design appear place in buildings under construction or operating buildings that have passed through essential changes in the project (Samofalov, Papinigis 2010; Love *et al.* 2014; Rumane 2011).

1. Standards regulating project documentation

Main law regulating requirements for the design of buildings in Lithuania is the Construction Law (Lietuvos respublikos... 1996). This law is in agreement with adjacent laws (Eurocodes) and considers the requirements applicable in the European Union. Executive legal notes are national technical construction requirements (STR 1.01.05:2007). All requirements prescribed in these requirements are compulsory. Other normative documents available for application are of recommendable nature and are applied by the discretion of a designer. In case, when all structural calculations and checks are made according to Eurocodes, it still has to fulfil the requirements of local regulations STR. This usually leads to a double-check of structural solutions. When talking about 'design and build' practice with very tight time schedules, processes of this kind of nature are time consuming and could possibly lead to mistakes in design calculations and a complicated situation on a construction site. In this case, modern design and advance monitoring methods should be applied (Aljassmi, Han 2014; Chen, Luo 2014; DBN V.1.2–5:2007; DBN V.2.2–24:2009; Hattab, Hamzeh 2015; MRDS 02–08; Perelmuter 2011).

According to national practice a building project is implemented using a one-stage or two-stage procedure (STR 1.01.06:2013, STR 1.05.06:2010). In case, when after the first stage a tender procedure for the choice of a general construction contractor is being carried out or if there is such a requirement in an agreement with the client a two-stage procedure is necessary. In order to be able to maintain a design quality at a high level and well organised design procedures it is highly recommended to practise a two-stage procedure (Gabrielaitis *et al.* 2012; Samofalov 2010; Samofalov *et al.* 2010), especially in a case of original and complex structural systems.

From the legal point of view, the design process starts with a confirmed design task. An outline project for complex architectural solutions and industrial buildings with modern technologies applied in it is a necessity. On the preliminary design stage (it is possible to perform geotechnical investigations on a construction site and inspection of existing (reconstructed, for example) building structures.

A technical project has to be detailed enough in order to be in conformity with valid regulations (STR 1.05.06:2010):

- understand the project concept;
- verify main decisions in expertise;
- estimate the construction price;
- select a general construction contractor;
- get a building permit;
- execute a working project.

Solving of design questions originated when performing surveys, additional investigations (for example, a building model test in an aerodynamic tube, Pavlovsky *et al.* 2012), demounting of existing structures and all the above-mentioned procedures are implemented during the technical project stage. The final technical project is delivered to the client (builder) as a separate set of documents.

The working project is executed according to all provisions given in the technical project. This design stage includes more detailed solutions, documents for mounting technological equipment, fabrication drawings etc.

The design process of the example project, considered in this paper (Fig. 2), has been divided into three stages: a project outline, a technical project and a working project, which has been prepared in parallel with construction works. There were two revisions of the technical project issued during the working project. The construction process took about 65% of the overall project duration. As the concept of the office building was ‘an open office’ and the client had no a ‘fixed’ contract for the tenants of the office (means no planning and functional requirements), the architectural and mechanical and all other parts of the project suffered many changes during all stages of design. The structural design according to total labour hours took about 85% of the overall project duration and was developed as follows: 15% for design concept; 20% for the technical project; 20% for revisions of the technical project and 45% for the working project, including minor changes not affecting the design concept.

In case of technologically innovative and complex structures the relevancy of designs has been checked by a natural testing of a structural fragment on the site (Fig. 3). For original complex structures a monitoring should be introduced (DBN V.1.2–5:2007; MRDS 02–08).

2. Project revision management

A design task for the technical project including goals for the structural design is initiated after the client (builder) has approved an outline project proposal.

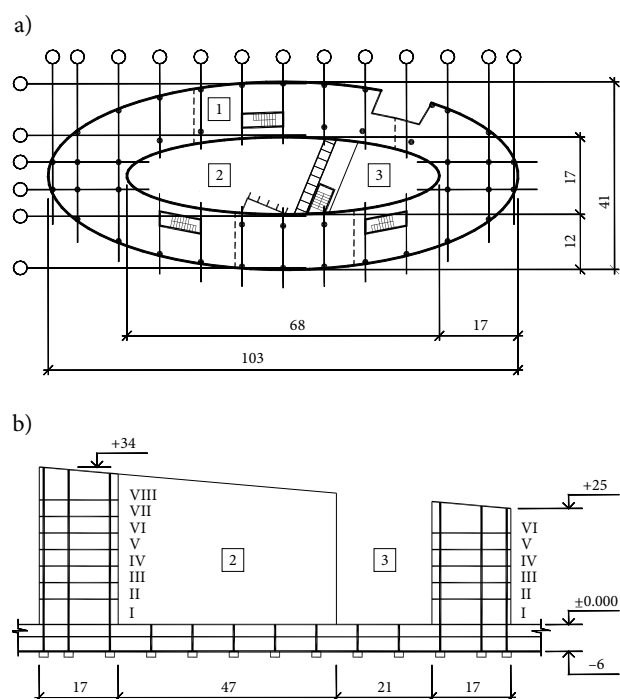


Fig. 2. A typical plan (a) and longitudinal section (b) of the considered building: 1 – a slab; 2 – the inside space; 3 – the open space



Fig. 3. On the site test of cantilevered steel stairs

The technical project stage starts after the design task is approved by the client (Fig. 4). The technical project consists of a series of technical documents, drawings and engineering calculations (STR 1.05.06:2010).

After the technical project has been finished it is then delivered to expertise. Expertise provides a project verification certificate. It goes either with notes about the necessary to implement or with project verification certificate including recommendations for the client (builder) to approve the project. In case when expertise provides negative notes on fundamen-

tal structural solutions (for example, irrational spacing of columns, badly assessed effect of groundwater on substructures etc.), the designer has to agree with the client on the question of updating the technical task. Afterwards, when a new design task is approved and a new technical project has been issued, it repeatedly goes to the expertise.

A well prepared technical task has to be worked out on three levels:

1. A global design task for the design manager – provided by the client (builder).
2. Specific tasks for managers of separate design parts – provided by the design manager.

3. Specialized inter-discipline tasks – provided by one design discipline manager to another (for example, key principles for fabrication technology).

The technical project approval of the client does not eliminate the designer's responsibility for the project. It simply shows the client principal agreement on design solutions. The client (builder) still has right to review the technical project and reasonably request for changes in the project even if the project is verified by expertise; or he also may ask for a new design task and the technical project prepared newly (Fig. 4).

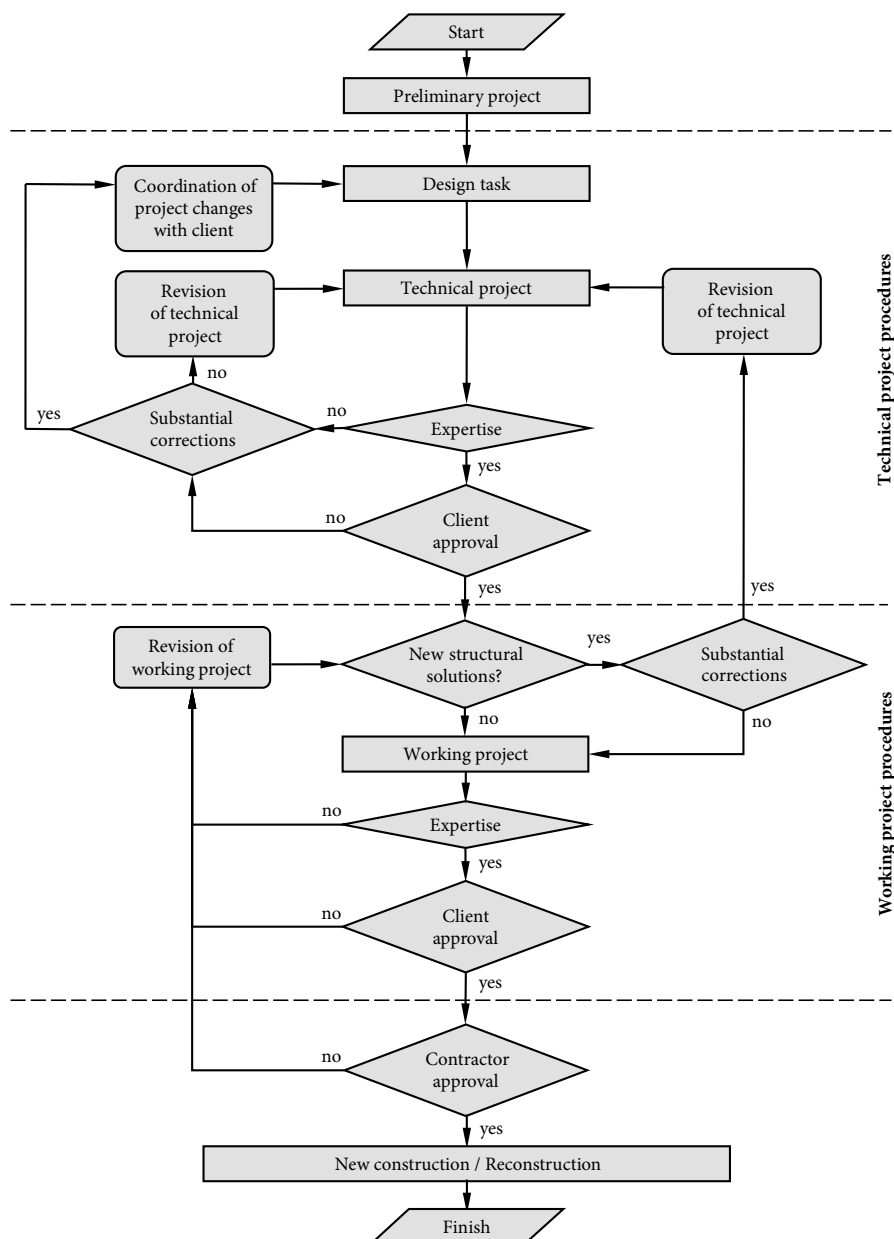


Fig. 4. A scheme for implementing design changes in structural project documentation

A tender procedure for the choice of a general construction contractor is initiated straight after the client approves the final technical project. The general contractor is then responsible for the management of the working project. Some parts of the project can be developed by manufacturers or subcontractors. It is undeniable that tender procedures between the contractor and subcontractors can last for a few years. This is not the case for the process of the working project, which starts in parallel with construction works on the site. This context negatively affects the quality of the working documentation and construction as well (Aljassmi, Han 2014; Love *et al.* 2014; Samofalov, Papinigris 2010).

The main structural frame in our example of the office building was designed using precast concrete structural members (columns, beams, slabs etc.) for the storeys and steel structure – for the roof (Fig. 5a). The general contractor has been chosen after an expertise of the primary technical project. He came with the an idea to change the structural framework from the precast to cast-on-site concrete with post-tensioned concrete slabs. In meantime there were 30 % of pile foundations erected on the site. This change led to recalculation of main structural scheme, revision “A” of the technical project, additional expertise and revision of the foundation working project. To say nothing about the challenges these changes provided for the development of the project, “B” revision of the technical project was released from the idea that post-tensioned concrete roof slab should be cheaper than the steel roof (Fig. 5b). In meantime there were four floors of the superstructure erected on the site. So, this fact led to a new evaluation again. Obviously, changes of such extent and order are intrusive and are considered as good catalysts for the probability of human errors and failures in structural design (Hattab, Hamzeh 2015).

The procedure of any working project verification is similar to the procedure applied in a technical project, although, it has two main differences. Firstly, it is possible according to technical construction requirements to issue the working project in several parts (for example, a working project part for underground structures, for substructures and so on). Secondly, no changes in design can be implemented during realization of the working project. The working project is intended for construction purposes and can only be changed if the technical project has been changed

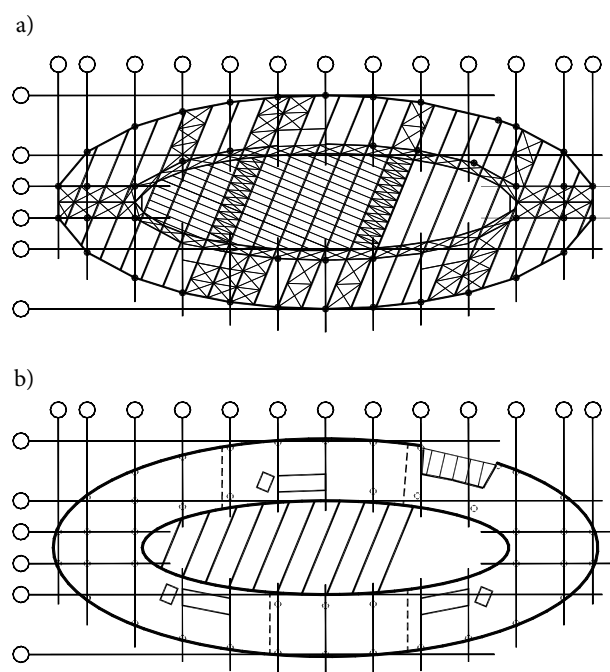


Fig. 5. A principal scheme of the roof: steel structures, initial and “A” revisions of the technical project (a); post-tensioned concrete structure, revision “B” of the technical project (b)

theretofore. It is a logical procedure, as the technical project stage is mainly for defining of principal design solutions, whereas the working project stage – mainly for detailing.

Sometimes the case occurs when general construction contractor chosen by the client offers changes in essential structural solutions (it means, a new edition of the technical project) during the working project stage. It is a near-to-conflict situation as the general construction contractor has already passed through the tender procedure (it means, he is familiar with the principles of the technical project) and was able to present his ideas about the structural design concept to the client.

A key point after finalizing of the technical project is getting a building permit. According to the last confinements in technical construction requirements (STR 1.07.01:2010), changes location or external dimensions of overall buildings structure of up to 1 m is a trivial change and there is no need for a new revision of the technical project.

There is a possibility to prepare a one-stage technical-working project in case when there is a need to release together the technical project and the working project. It is a logical choice, as this procedure is well known in practice. However, several routines have to be made in advance – an update of a technical design

task, agreement on the choice of a general construction contractor (more likely construction extents and material quantities will be changed), revisions if there is a need for a new building permit etc. A special attention should be given to the quality of such technical-working project. There cannot be any ambiguities and uncertainties in the project when choosing one-stage design procedure, as well as no links associated with design solutions to the documents that will be released in the working project.

When considering complex structures even with a fixed and precise design task, designing and built practice can only be successfully implemented, when there are enough engineering specialists, assigned to the project. The current experience in Lithuania shows that there are usually several structural engineers (this number is up to ten times lower than in other European countries) responsible for the analysis, design, documentation and coordination of such structural project. Besides the structural system of the building, the responsibilities include also: thermo physical, waterproofing, fire, acoustic etc. performance of the building. The current situation alongside with a low cost of design services and growing complexity of structural systems affects the quality of complex building projects.

It is necessary to have a very clear project organizational scheme, involving multi-disciplinary coordination procedures, ranges of responsibility, documentation routines etc. When implementing design changes in the project along with the execution of construction works on the site an application of a Building Information Model (BIM, Fig. 6) in the design process

could possibly speed up the process and eliminate a lot of coordination errors (Chen, Luo 2014; Hattab, Hamzeh 2015; Miettinen, Paavola 2014).

3. Engineering calculations during designing

You will not find any divisions into a separate technical design and working project stages in any of academic textbooks of structural mechanics when talking about engineering calculations. Obtaining all necessary design parameters for complex mechanical system with satisfactory precision by solving a single engineering task is irrational (Perelmuter 2011).

It is important to note, that analytical model of the structural system highly depends on peculiarities of each building structure, as well as on construction site conditions. The quality of engineering calculation results rises step by step when solving (by modelling, systematization results etc.) separate problematic structural tasks, technological aspects of the erection of structural members, eliminating some assumptions from conventional analysis methodology, reducing the amount of uncertainties and refining the input parameters for a global analytical model (Fig. 7). It is recommended to use different modelling precision (one-dimensional beams, plates, mixed systems, plane frames, etc.), when performing preliminary design calculations, specifically determining the static, dynamic or kinematic factor (Perelmuter, Slivker 2003). Results obtained from the global structural analysis (Fig. 8) may show some singularities signalling about the inconsistency of the global analytical model (Fig. 9).

The special attention, when solving complex design tasks, has to be paid to structural nonlinearities, which are physical, geometrical and technological (Samofalov 2010; Perelmuter, Slivker 2003). When solving nonlinear tasks, it is often useful to choose one type of nonlinearity and involve strict assumptions, contrarily the formulation of a problem will be ill-founded and therefore results – unreliable (Atkočiūnas 2011; Atkočiūnas, Venskus 2011). There are always some difficulties for a structural engineer to evaluate nonlinearities, as it is a time consuming task that requires high qualification of the specialist. The complex building design is not a scientific timeless investigation; it has fixed well known dates for finalizing the project (Blaževičius, Šalna 2013; Samofalov, Cvirka 2010). A right choice would be to issue the first revision of a project with approximate results obtained from non-

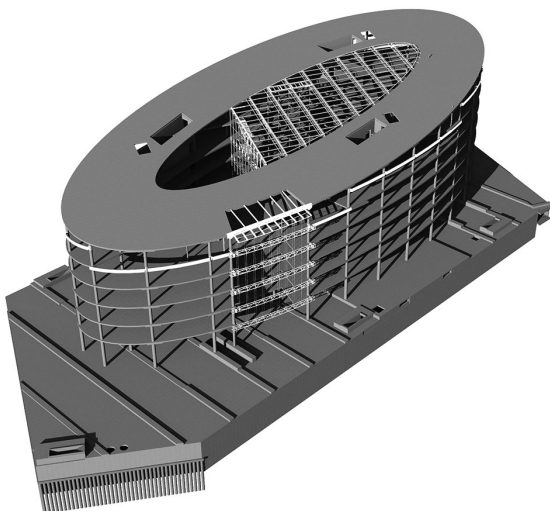


Fig. 6. A spatial solid structural model of the example building

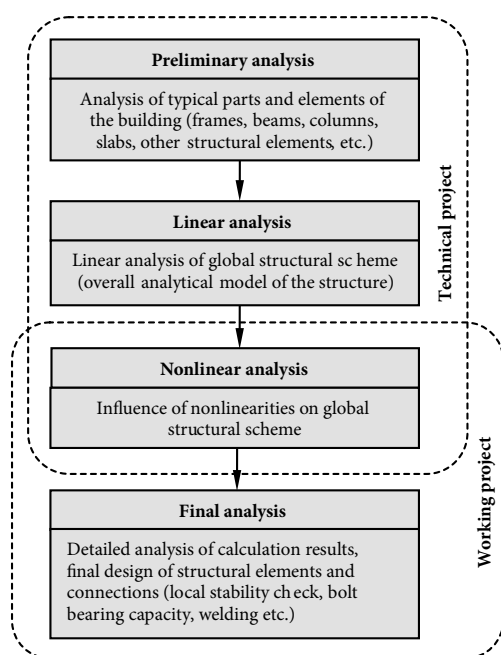


Fig. 7. Structural analysis in different stages of the project

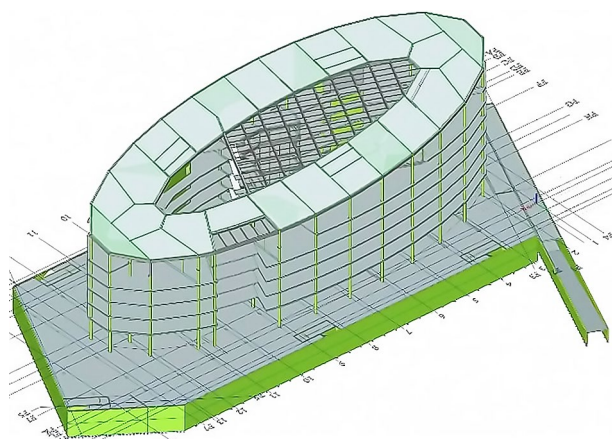


Fig. 8. A global structural scheme of the building

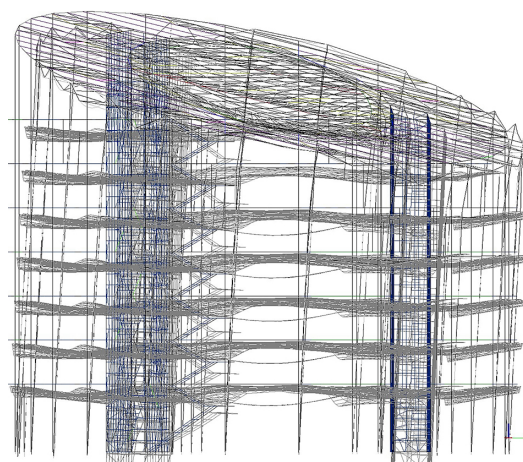


Fig. 9. A deformed shape of the structure: a combination of self weight, live load and wind actions

linear calculations. Afterwards, while the client (builder) goes through the building permit and the general contractor tender procedure perform the detailed computing of structural nonlinearities and formulate tasks for the working project. One should note, that the preliminary evaluation of nonlinearities should be of a satisfactory precision, whereas detailed calculations of nonlinearities should not change the primary structural solutions presented in the technical project.

Final analytical calculations performed during the working project usually are very restricted in time, as they are executed in parallel to building works on the site. All calculations are divided into separate design tasks of an individual member. This allows for several engineers of a relatively low qualification to perform simultaneously analytical calculations.

It is a very complicated procedure to issue a revision of the project including fundamental changes in the analytical model. Especially, this is the case when several years have passed after the final calculations were made and the technical project has been issued. All changes to the analytical model have to be implemented very carefully, as these changes may affect the continualness of the information involved in the model. This work is quite thorough. In the design practice of complex building structures a decision to create a completely new analytical model is often made while eliminating all imperfections of a present model.

Returning to the practice in judicial and insurance expertise, there were cases when fundamental mistakes in structural solutions were taken place with a new project revision. It is a good practice to check behaviour of structures on the site by implementing static or dynamic tests. In our example project such tests were carried out for cantilevered steel stairs (Fig. 3). Stairs were loaded and unloaded in several steps from 1 to 5 kPa. The results (Table 1) showed that measured deflections are higher compared to those given by numerical simulation. These differences were caused due to a real horizontal displacement of 0.29 mm in one of four supports of the structure. This deflection was assumed as trivial as far as the horizontal displacement in a horizontally loaded bolted connection is a normal phenomenon.

One should notice, that the proper design process management and quality control of engineering calculations plays a key role when designing complex building structures.

Table 1. Experimentally measured and numerically calculated vertical deflections of cantilevered steel stairs

Load, kPa	Measured deflections (mm) at the point of the cantilever end		
	Left	Centre	Right
0.00	0.00	0.00	0.00
1.00	0.64	0.72	0.82
0.00	0.00	0.00	0.00
2.00	1.12	1.40	1.64
0.00	0.06	0.23	0.32
3.70	2.27	3.05	3.81
0.00	0.12	0.81	0.80
5.00	2.84	4.11	5.11
3.80	2.28	3.86	4.41
2.00	1.28	2.37	2.68
1.00	0.71	1.86	1.85
0.00	0.16	1.08	0.96
Load, kPa	Calculated deflection (mm) at the same points		
	Left	Centre	Right
5.00	2.20	2.70	3.60

4. Revision management of drawings

Sets of documents according to design codes in Lithuania are regulated on three different levels:

1. The complete project including all parts.
2. Separate project parts.
3. Separate drawings and technical documents.

All trivial changes in project (for example, correction of grammar mistakes) are made during the design process and are performed without an assigning new edition to the project. In a case, when the project is already issued and verified (by expertise and digital project transferred to national archive 'Infostatyba') it is enough to inform the client about trivial corrections by a message. Similarly common corrections are made during the working project.

When essential changes to the technical project have to be made, especially when fundamental mistakes in analytical calculations or drawings have been found, the design manager has to be informed and take the following actions:

- organizes a new design revision if the project is not yet verified;
- in case the project is verified, promptly inform the client about the situation and offer to organize a project revision, starting from the development of new technical task.

Let's see some examples.

The 1st example: Say, due to certain circumstances the technical project has suffered essential changes. These changes have been made to the explanatory letter and 7 drawings. In this case:

- revision mark 'A' is assigned to the explanatory letter and to each of 7 drawings;
- revision mark 'A' is assigned to the set of documents with the explanatory letter and same 7 drawings;
- revision mark 'A' is assigned to a part of the project with revised documents;
- the complete project of the building gets a revision mark 'A';
- the project of a group of the buildings gets a revision mark 'A'.

The circumstances of the new revision should be explained in the explanatory letter. Notes on changes are given in revision tables in each revision 'A' drawing (Fig. 10).

The 2nd example: Say, it has been decided to change the shape of the building from circular in plan to a square one. The project change of that extent touches almost every part of the technical project (probably, only external engineering networks on the site will not change obviously). In this case revision mark 'A' is assigned to:

- all revised drawings and documents;
- volumes of drawings including revised ones;
- project parts including revised volumes;
- the overall project of the building;
- the overall project of the group of buildings.

Project revision 'A' is issued with revised and old documents and document volumes.

In the current engineering practice a revision of separate drawings or documents is almost a daily or weekly activity. In the example project of the office building, which is above-mentioned in this paper, the amount of changes in the documentation compared to the first revision of the technical project is quite significant (Table 2).

Conclusions and recommendations

The survey, presented in this article, allows making the following conclusions and recommendations:

- even if nowadays essential changes in the building design is such a frequent phenomenon, design codes and literature gives a few information about how to manage the process of mak-

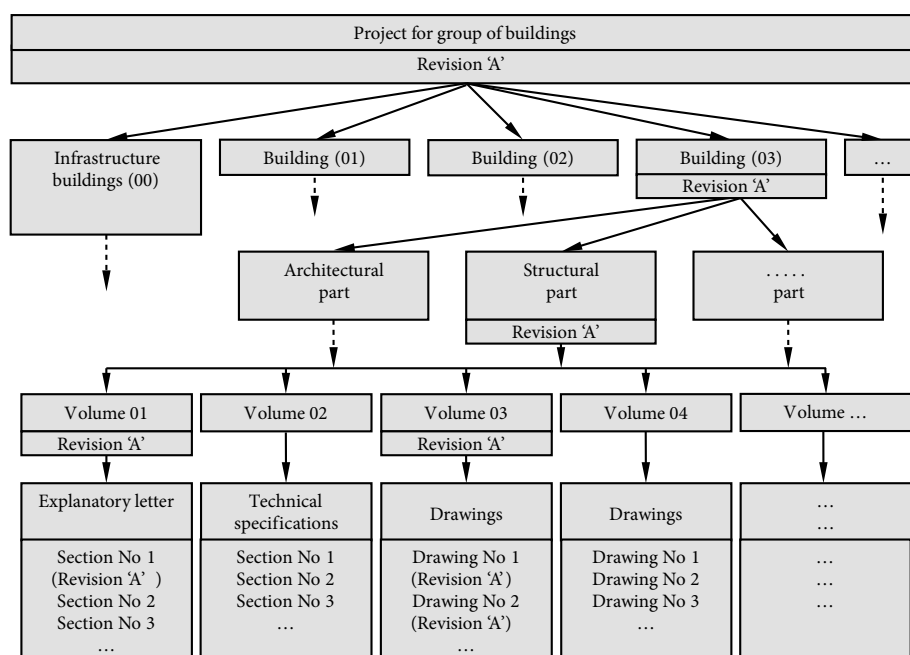


Fig. 10. A principal scheme for the assignment of revision marks to separate documents and volumes of the project

Table 2. Rough estimate of total changes in the example project

Design stage	Changes in documentation, %
1. Technical project	95
1.1. Explanatory letter	10
1.2. Technical specifications	15
1.3. Engineering calculations	30
1.4. Drawings	30
1.5. Material quantities	10
2. Working project	30
2.1. Technical specifications	5
2.2. Engineering calculations	10
2.3. Drawings	10
2.4. Material quantities	5

ing a project revision. The practice shows that changes in projects are made under bad feelings of each practicing engineer, not invoking any scientific evidence. We recommend, that in such cases the design results have to be checked by onsite tests of structures;

- in a case, when there is a need for a change in a project, a plan for implementing project changes has to be arranged and agreed with the client. Such a plan should include a financing program, working schedules with terms for engineering recalculations, preparation of drawings, coordination of designs in each and between project parts etc.;

- design changes should be revised by engineers of other project parts and adjusted if necessary;
- special attention should be paid planning of a working schedule for the revisions of drawings and for the issuing of new sets of drawings. Practice shows, that this task is time consuming as compared to other redesigning tasks.

It is often useful to apply knowledge in managing processes cumulated by research organizations (Wu, Hamada 2000). Useful methods and guides for building project management can be found in articles published by other authors (Kaklauskas *et al.* 2011; Kanapeckienė *et al.* 2010).

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Michail SAMOFALOV. Prof. at the Department of Marine Engineering, Klaipėda University, Lithuania. Assoc. Prof. (2011) at Vilnius Gediminas Technical University. Since 2006 an expert of JSC “Projektų ekspertizė”. A certified structural designer and expert in civil, industry and bridge engineering of Lithuanian Ministry of Environment. Research interests: structural designing of complex buildings, numerical simulation, non-linear structural analysis, management and examination of design solutions.

Vytautas PAPINIGIS. Assoc. Prof. at the Department of Reinforced Concrete and Masonry Structures, Vilnius Gediminas Technical University (VGTU), Lithuania. Since 2000 director and expert of JSC “Projektų ekspertizė”. A certified expert in civil, industry and bridge engineering of Lithuanian Ministry of Environment. Research interests: numerical and experimental analysis of reinforcement structures, fire actions on bearing structures, management and examination of design solutions.

Virmantas JUOCEVIČIUS. Head engineer at the Department of Structures of JSC “ASD Project” (2012). PhD (2011) in Civil Engineering at Vilnius Gediminas Technical University. A certified structural engineer in civil engineering of Lithuanian Ministry of Environment (2008). Research interests: structural designing of complex buildings, numerical analysis, risk analysis.