Geotechnical engineering education and practice in Croatia

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ABSTRACT: The National report on Geotechnical engineering education and practice in Croatia is presented. A historical overview is included. The main emphasis is on the changes that occurred in the higher education system according to the Bologna process. Geotechnical courses are offered at four Croatian Universities and one Polytechnics according to both the old and the new curricula. It is shown that geotechnical education has a long tradition in Croatia, and it includes continuing education for practicing engineers. The recent geotechnical practice in Croatia is presented through the major geo technical project, which is the Croatian motorway system, and examples of construction in urban areas are given.

1 INTRODUCTION

Geotechnical education has a long tradition in Croatia. Even though there are only 4.4 million inhabitants, there are four Universities with six Faculties, and one Polytechnics, which include geotechnical courses in their curricula. The oldest University is the one in Zagreb, founded in 1669. The other three are the University of Osijek, University of Rijeka and University of Split, located in the respective cities (Fig. 1). The four Universities are organized so that they consist of different Faculties, each Faculty functioning as an autonomous institution headed by the Dean. The Polytechnics-like courses of 6 semesters are offered in Split, Rijeka and Osijek within the respective Universities, whereas the Polytechnics in Zagreb is a separate institution offering a variety of studies.

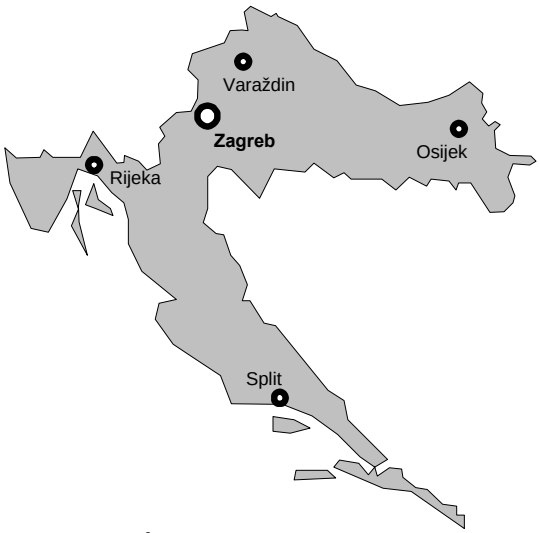

Figure 1. Map of Croatia.

In 2003 the Croatian Parliament has accepted the new Law on Research and Higher Education, according to which all institutions of higher education in Croatia have to restructure their curricula according to the Bologna process and start with new programs from the academic year 2005/2006. There has been a lot of turmoil and conflicting discussions regarding the implementation of this Law, but all the institutions of higher education have, indeed, started with their newly restructured curricula, accredited by the National Agency for Higher Education, on time.

The geotechnical practice in Croatia has been quite intensive in the last decade. The single major civil engineering project in Croatia, ever, has been the construction of the motorway system, now in its final stage, with demanding deep cuts, tunnels, bridges and viaducts. Many deep excavations, mostly in urban areas, have been constructed with the use of sophisticated numerical analyses, geotechnical monitoring, interactive design, and new construction technologies. The interactive design includes extensive monitoring during construction and it has also been used during the motorway tunnel construction. Other projects include deep foundations, soil improvement and the stabilization of landslides. Croatia also has a long tradition in building hydropower systems, embankments and dams.

The major geotechnical projects are often done in consultations with University professors. There has been a long tradition of interaction between academia and geotechnical practice in Croatia, which was particularly intensified by the late professor Nonveiller, in memory of whom the Croatian Society for Soil Mechanics and Geotechnical Eng ineering holds the traditional annual Nonveiller Lectures.

2 GEOTECHNICAL EDUCATION

Croatia has had the binary system in higher education consisting of University studies, Polytechnics-like studies within Universities and separate Polytechnics studies to a lesser extent. Each of the four Croatian Universities has the Faculty of Civil Engineering, where geotechnical courses like Soil Mechanics, Foundation Engineering and Engineering Geology have traditionally been included in the curricula. The University of Zagreb also has the Faculty of Mining, Geology and Petroleum Engineering, which offers several geotechnical courses. It may be interesting to note that there is also the Faculty of Geotechnical Engineering in Varaždin, belonging to the University of Zagreb.

The University studies at the above 6 Faculties still consist of the old 9 semester programs, except for the first year students who have all enrolled in 2005 according to the new programs in line with the Bologna process. The old programs are no longer offered to the first year students, but they will continue to be carried out for all those who have enrolled up to the year 2004, for another four years.

The Polytechnics-like studies consist of the old 6 semester programs. Geotechnical courses have been offered at four higher education institutions in Croatia which carry out such studies.

2.1 *Historical overview*

The undergraduate studies in civil engineering started in 1919, when the Technical College was founded in Zagreb. The famous professor Stephan Timoshenko was teaching at the College for two years from 1920 and he founded the laboratory for testing structural elements in Zagreb (Szavits-Nossan 2000).

The requirements for awarding the title of Doctor of Technical Sciences were set as early as 1920, and the first civil engineering Doctor was promoted in 1922. The first title of Diploma Engineer in Civil Engineering was awarded in 1923. The Geotechnical Department was founded in 1939 and the first geotechnical laboratory in Croatia was set to work for students in 1940.

The Technical College became Technical Faculty and a part of the University of Zagreb in 1926. In 1956 the number of students increased to almost 4000, so that the Technical Faculty was split into four Faculties, one of which was the Faculty of Architecture, Civil Engineering and Geodesy. In 1962 this Faculty was split into three independent institutions, so that the Faculty of Civil Engineering was established at the University of Zagreb. In 1964 the Faculty of Mining, Geology and Petroleum Engineering also became part of the University of Zagreb. Faculties of Civil Engineering were founded in 1971 at the Universities of Split and Rijeka, and in 1985 at the University of Osijek. The Faculty of Geotechnical Engineering was founded in 1990.

Prof. Rieszner started teaching the courses Soil Mechanics and Foundation Engineering in 1942. From 1960 Soil Mechanics, and from 1965 Foundation Engineering, were taught by the well-known Prof. E. Nonveiller, who took classes with Prof. Karl Terzaghi and graduated at the Technical University in Vienna.

The postgraduate studies were first held in 1963 at the Faculty of Civil Engineering at the University of Zagreb. The two years program, leading to the title of Master of Technical Sciences, offered right away specializations in Structural and in Geotechnical Engineering. The first Ph.D. thesis in geotechnical engineering was defended in 1977.

An interesting initiative was undertaken in 1977, when the Faculty of Civil Engineering in Zagreb was merged with the Civil Engineering Institute of Croatia. At that time it was proclaimed that the newly formed institution would encourage the interaction between education, research, consulting and practice. Later on, Faculties of Civil Engineering in Split, Rijeka and Osijek joined this institution, even though they still belonged to their respective Universities. Research funds were increased due to the income from industry. However, the gap between two different concepts of education and practice, one by professors, and the other by practicing engineers, was never bridged. Along with political turmoil, which occurred in former socialist countries in the late eighties, this huge institution broke down to the original constituents in 1991 (Szavits-Nossan 2000).

2.2 *The old curricula*

Up to 2004 the students were enrolling according to the old curricula. In 2005 new curricula based on the Bologna process were inaugurated at all Croatian Universities and Polytechnics. First year students now follow the new curricula, whereas all the others still follow the old ones, and they are allowed to graduate according to these old curricula.

The old higher education curricula were based on the continental system under the German influence, as opposed to the Anglo-Saxon and the French systems. One of the characteristics of the continental system is that the planning and taking examinations are to a certain extent left at the liberty of students. This circumstance, among others, has lead to the fact that the actual study duration is usually at least 50% longer than the nominal one, and the number of drop-out students is high.

According to the old curricula, all Faculties offering geotechnical courses award the title of Diploma Engineer after the completion of eight semesters of courses and one semester of work on the Diploma thesis. Civil engineering Polytechnics-like studies, which also offer geotechnical courses, award the ti-

tle of Engineer after five semesters of courses and one semester of work on the graduating thesis. The old higher education system at technical institutions, which include geotechnical courses in their curricula, is illustrated in Figure 2, where the arrows show possible paths for the job market.

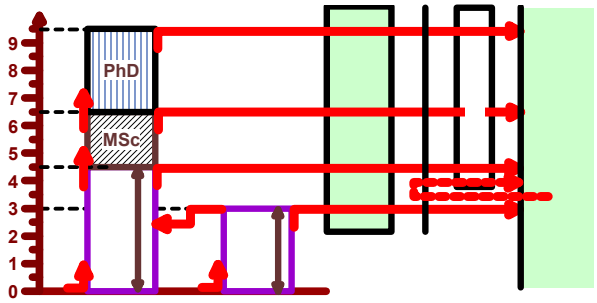

Figure 2. The old higher education system (Szavits-Nossan and Korlaet 2005).

Soil Mechanics and Foundation Engineering courses are taught during the fifth and the sixth semesters of the University studies. All Polytechnics-like studies offer a single geotechnical course during the third semester.

Geotechnical specialization is still offered at the Faculty of Civil Engineering in Zagreb, in the form of a branch study chosen by the students when they enter the fourth year. The first students entered the geotechnical branch study in Zagreb in 1999. The geotechnical part of this branch curriculum is given in Table 1.

Table 1. Geotechnical courses for geotechnical specialization at the Faculty of Civil Engineering, University of Zagreb (Szavits-Nossan 2000).

Course title	Semester	Hours*	
Geotechnical Investigations	VII	30+30	C
Applied Soil Mechanics	VII	45+30	C
Rock Mechanics I	VIII	45+30	C
Foundation Engineering II	VIII	45+30	C
Embankment Structures	VIII	30+30	E
Geotechnics of Underground Structures	VIII	30+30	E
Flexible Foundation Structures	VIII	30+30	E
Retaining Structures	VIII	30+30	E
Numerical Modeling in Geotechnics I	VIII	30+30	E

* Hours of lectures and classwork per semester; C for compulsory, E for elective courses.

The curriculum of the Faculty of Geotechnical Engineering was intended to provide students with specialized geotechnical knowledge, generally used either in civil engineering or in mining. There are two branch studies, geotechnical and hydrotechnical, both leading to the degree of Diploma Engineer in Geotechnical Engineering. Students select one of the two branch studies when they enter the fourth year. The shortened curriculum, with courses from the geotechnical branch in the seventh and eighth semesters, is given in Table 2.

Table 2. Selection of courses from the curriculum (geotechnical branch) at the Faculty of Geotechnical Engineering, University of Zagreb (Szavits-Nossan 2000).

Course title	Semester	Hours per semester Lecture	Classwork
Introduction to Geotechnics	I	30	0
Soil Mechanics I	V	45	30
Rock Mechanics	V	45	15
Geotechnical Structures	V	30	15
Drilling	V+VI	30+30	30+15
Geophysics	V+VI	30+15	15+15
Mining	V+VI	45+ 0	0+30
Soil Mechanics II	VI	45	30
Environment Protection	VI	30	0
Geotechnical Investigations	VI	30	15
Foundation Engineering I	VII	30	30
Soil Dynamics	VII	30	30
Soil Improvement	VII	30	30
Geotechnical Works for Roads	VII	45	30
Stability of Slopes	VII	30	30
Geotechnical Laboratory	VII	0	45
Foundation Engineering II	VIII	30	30
Num.Modeling in Geotechnics	VIII	30	45
Geotechnical Design	VIII	30	30
Earth Dams*	VII+VIII	30+30	15+15
Underground Structures*	VII+VIII	30+30	15+15

* Elective courses; all other courses are compulsory.

Table 3 summarizes the number of geotechnical courses at the undergraduate level at all institutions in Croatia.

Table 3. Educational programs in Croatia, which include geotechnical engineering courses (Szavits-Nossan 2000).

Program	Duration in semesters	Number of institutions	Number of courses Compulsory	Elective
CE (P)*	6	4	1	0
CE (U)	9	4	1-2 (1)**	1-9 (4)
GE (U)	9	1	19	2
ME (U)	9	1	1	3

* CE: Civil Engineering, GE: Geotechnical Engineering, ME: Mining, Geology and Petroleum Engineering; (P): Polytechnic-like studies for Engineer, (U): University for Diploma Engineer.
** The number in parenthesis denotes the average.

Postgraduate geotechnical courses were offered at three out of the four Universities, each having a different curriculum. The Civil Engineering Faculties of Zagreb, Split and Rijeka were awarding the degree of Master of Technical Sciences. The Civil Engineering Faculties of Zagreb and Split award the degree of Doctor of Technical Sciences.

The program for the MSc degree included two semesters of courses and two semesters for the thesis. After the completion of this program, it took two additional semesters of courses for the doctoral program, followed by another two semesters for the thesis. Those candidates who applied for the doctoral

program, without having achieved the MSc degree, took four semesters of courses.

The postgraduate geotechnical courses offered at the Faculty of Civil Engineering, University of Zagreb are listed in Table 4. Five courses from Table 4 were required for the MSc degree, and another three for the doctoral degree.

Table 4. Postgraduate geotechnical courses for geotechnical specialization at the Faculty of Civil Engineering, University of Zagreb (Szavits-Nossan 2000).

Course title	Hours per semester	
	Lecture	Classwork
Soil Dynamics	30	15
Theoretical Soil Mechanics	30	15
Special Topics of Foundation Engineering	30	15
Improvement of Foundation Soil and Rock	30	15
Rock Mechanics II	30	15
Soil Consolidation and Creep	30	15
Numerical Modeling in Geotechnics II	30	15
Geotechnical Observation and Monitoring	15	30
Geotechnics in Environment Protection	30	0
Seepage	30	15

2.3 *The new curricula*

Croatia officially joined the Bologna process by signing the Prague communiqué in May 2001. The Law on Research and Higher Education followed in July 2003, requiring all institutions of higher education to adopt the three-tier BSc/MSc/PhD curricula by September 2005. At the same time four Croatian Universities, backed by several partner institutions from EU countries, including the Technological Educational Institution of Athens – TEI, Athens, were granted in 2003 a TEMPUS JEP project aimed at restructuring their civil engineering curricula along the guidelines of the Bologna process.

At the start of the procedure of restructuring all curricula, three main problems emerged (Szavits-Nossan and Korlaet, 2005). The first one was to squeeze the existing Diploma Engineer plus MSc degree curricula, of the nominal duration of 6.5 years, into 5 years of the BSc plus MSc programs. A lot of heated discussions on this subject resulted in the decision to form the body of knowledge a student should acquire during the five years of study.

The second problem was to find a balance between basic, or theoretical courses, and more practical, or engineering courses, for the first two cycles of education, as shown in Figure 3. In this Figure, the second column, denoted as Bologna 1, shows the unbalanced programs, where a simple cut is made in the existing curriculum after the third year of study. The third column, denoted as Bologna 2, shows the balanced program, where courses are divided between the two cycles in such a way that both cycles contain a balanced number of basic and engineering courses. This is especially important because the first cycle must have the employability relevance. The balanced programs were set up by rearranging the contents of most courses in order to obtain more coherent curricula.

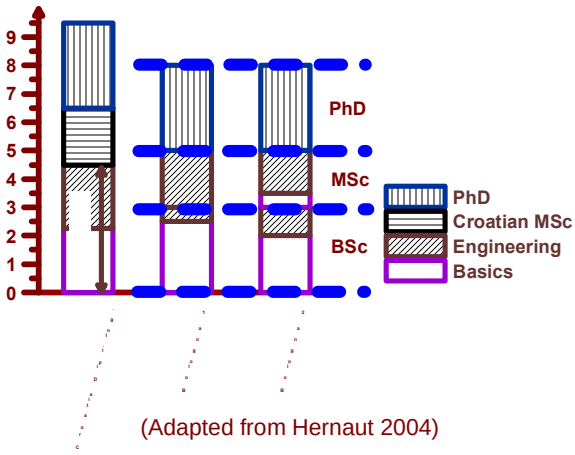

Figure 3. Balance between basic and engineering courses (Szavits-Nossan and Korlaet, 2005).

The third problem, which also evoked many discussions, was to set the duration of each of the first two cycles of education, the third being the postgraduate level, having the duration of 3 years. The different approaches to this problem, that were discussed, are shown in Figure 4. The first option, the 3+2 duration, was accepted as the most balanced one. It was considered that the other two options were not balanced enough, namely the 3.5+1.5 option has a draw-back due to the short period between the fall and spring semesters, which defines the line between the two cycles. Students would not have enough time to graduate from the first cycle and start following the second one. It was considered that in the 4+1 option, one year for the second cycle would not provide enough time for students to cover all the necessary engineering courses required for the MSc degree. The cycle duration of 3+2 was also convenient because Polytechnics-like studies traditionally have had three years programs for the Engineer degree, and employers in Croatia are familiar with it.

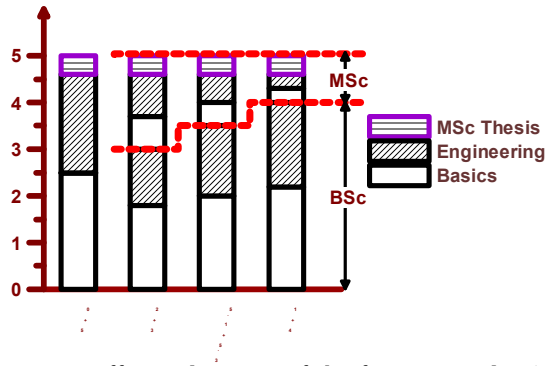

Figure 4. Different durations of the first two cycles (Szavits-Nossan and Korlaet, 2005).

The new curricula consist of three consecutive cycles: the undergraduate, graduate and postgraduate

studies with the duration of 3+2+3. So far, the first two cycles have been accredited by the National Agency for Higher Education at all Croatian Faculties which include geotechnical courses in their curricula and at the Zagreb Polytechnics. According to the new Law on Research and Higher Education, the Polytechnics-like studies in Split, Osijek and Rijeka will have to exit from their respective Universities and be formed as separate institutions.

The work on the TEMPUS project enabled the cooperation between the four Croatian Faculties of civil engineering in order to enhance the student mobility by coordinating the curricula restructuring. The result is that similar first cycles have been adopted at all four institutions.

Geotechnical courses offered in the first cycle at the Faculty of Civil Engineering in Zagreb are shown in Table 5. Students have enrolled according to the new program in 2005. The title awarded after completing the first cycle is bacclaureus/baccalaurea in Civil Engineering. No specializations are offered at this level of study. The total number of ECTS credits is 180.

Table 5. Geotechnical courses in the first cycle at the Faculty of Civil Engineering of the University of Zagreb (BSc).

Course title	Semester	ECTS	Hours per semester Lecture	Classwork
Applied Geology*	IV	3	30	0
Soil and Rock Mechanics	IV	6	45	30
Geotechnical Engineering	V	6	45	30

* Elective course; other courses are compulsory.

The graduate study at the Faculty of Civil Engineering in Zagreb offers 7 specializations, among which is also the geotechnical specialization. The title awarded after graduation is MSc in Civil Engineering. The total number of ECTS credits is 120. Geotechnical courses offered at this level are shown in Table 6. This list of courses is similar to the one from the old curriculum.

Table 6. Geotechnical courses in the second cycle at the Faculty of Civil Engineering of the University of Zagreb (MSc).

Course title	Sem.	ECTS	Hours per semester Lecture	Classwork
Geotechnical Laboratory	I	7.5	30	45
Flow Processes in Soil and Rock	I	6	30	30
Soil Mechanics	I	7.5	45	30
Rock Mechanics	II	6	30	30
Foundation Engineering	II	6	30	30
Geotechnical Num. Modeling	II	7.5	30	45
Field Investig. and Monitoring	III	6	30	30
Earth and Retaining Structures	III	6	30	30
Hydrogeol. and Engng Geol.	III	3	30	0
Geotechnical Design	IV	6	30	30
Underground Structures*	III	6	30	30
Environmental Geotechnics*	III	3	30	0
Soil Dynamics*	III	6	30	30
Improvement of Soil and Rock*	IV	6	30	30

* Elective courses; all other courses are compulsory.

The postgraduate studies for the PhD degree have not yet been accredited. At the Faculty of Civil Engineering in Zagreb, 7 postgraduate specializations are proposed. The total number of ECTS credits is 180, out of which 48 credits are awarded for classes, 12 for research and 120 for the doctoral thesis. The geotechnical courses in this program are given in Table 7. The Faculty of Civil Engineering in Split also proposed geotechnical courses in their postgraduate program.

Table 7. Geotechnical courses in the third cycle at the Faculty of Civil Engineering of the University of Zagreb (PhD).

Course title	ECTS	Hours per semester Lectures
Mechanical Soil Behavior	10	45
Rock Engineering	10	45
Soil-Structure Interaction*	6	30
Nondestr. Geotech. Testing*	6	30
Triaxial Testing*	6	30
Flow Proc. and Soil Deform.*	6	30
Hydrogeology of Karst*	6	30

* Elective courses; other courses are compulsory.

Geotechnical courses are also offered in the second cycle at the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb, and at the Faculties of Civil Engineering of the Universities of Split, Osijek and Rijeka.

The Faculty of Geotechnical Engineering of the University of Zagreb has also restructured its curriculum and it now offers three specializations in the 3+2 program: geotechnical, hydrotechnical and geoenvironmental. All three specializations start in the third year of the first cycle.

The Zagreb Polytechnics has also inaugurated two cycles of studies with the duration of 3+2 for Civil Engineering. The title awarded after the first cycle (also 180 ECTS) is the same as for the University studies, whereas the title acquired after the second cycle with 120 ECTS is Specialist in Civil Engineering. One of the specializations offered in the first cycle of Civil Engineering is called Environment in Civil Engineering. The geotechnical courses, which are compulsory for all civil engineering specializations, are given in Table 8.

Table 8. Geotechnical courses in the first cycle at the Zagreb Polytechnics (compulsory for all civil engineering specializations).

Course title	Semester	ECTS	Hours per semester Lecture	Classwork
Elementary Geology	II	2	15	15
Soil Mechanics	III	5	30	30
Geotechnics	IV	5	30	30

There is no geotechnical specialization offered in the second cycle at the Zagreb Polytechnics. Geotechnical courses included in the Civil Engineering, which are all compulsory, are shown in Table 9.

Table 9. Geotechnical courses in the second cycle at the Zagreb Polytechnics (compulsory for Civil Engineering).

Course title	Semester	ECTS	Hours per semester	
			Lecture	Classwork
Advanced Meth. in Geot.	III	6	30	30
Solid Waste Disposals	II or III	6	30	30
Geotechnology	III	5	30	30
Tunnels	III	5	30	15

2.4 *Continuing education*

The continuing geotechnical education has been offered to practicing engineers since 1957 in the form of seminars organized by the Croatian Society of Civil Engineers. These seminars became very popular. The first geotechnical seminar was held in Zagreb with the title Geomechanics. From then on, the seminars have been regularly held once a year with the merit of several experts who were maintaining the profession up to date, and forwarding their knowledge and experience to engineers (Szavits-Nossan 2000).

Over the years, the seminars have covered a wide range of topics. Practical Geomechanics, Applied Geomechanics and Foundation Engineering were the most common titles of seminars until 1985. Typical titles of seminars held from 1985 are given in Table 10. Lectures are held during two or three days, the whole day long, to 30 participants on average. Written materials are prepared for participants.

Table 10. Typical titles of Geotechnical seminars for practicing engineers since 1985 (Szavits-Nossan 2000).

Topics of soil mechanics and foundation engineering; underground works for hydrotechnical structures (1985)
Pile foundations; geotechnical anchors (1987)
Soil dynamics; constructing in weak rock (1988)
Retaining structures; constructing in weak rock (1989)
Geotechnical aspects of hydrotechnical structures (1990)
Selecting the optimal foundation: errors and corrections (1991)
Computers in geotechnical engineering (1992)
Remedial and strengthening of foundations (1993)
Construction under and between buildings (1997)
Geotechnical problems in transportation engineering (1999)

3 GEOTECHNICAL PRACTICE

There are many geotechnical companies in Croatia. Civil engineering, in general, has been a very prosperous branch ever since Croatia gained independence in 1992. Numerous investments are made and there are no problems with hiring engineers for geotechnical construction. Sophisticated laboratory tests and numerical modeling accompany the design of large structures. A very good cooperation has traditionally been established between University professors and practicing engineers.

As stated in the introduction, the major geotechnical project has been the construction of the Croatian motorway system. This is the reason why special emphasis is made on this project, which will result in 1200 km of motorways in Croatia

Most large projects include the interactive design, where monitoring instruments are installed at the construction site in order to check whether the soil or rock mass is behaving according to the design, or contingency measures have to be taken in order to secure the structure. This is illustrated with two examples of deep excavations.

3.1 *Motorways*

The motorway system has been the major civil engineering construction in Croatia in the last decade and will continue to be so in the next five years. Figure 4 shows the map of Croatia with all the motorways.

The largest investment and civil engineering undertaking in Croatia has been the construction of the motorway A1, connecting two largest cities in Croatia, the capital Zagreb and Split. This motorway, connecting the North and the South of the country has been planned since the early seventies of the last century. It has a tremendous importance for tourism and for Croatian economy in general. The inauguration of this motorway was celebrated in Croatia in 2005.

The construction of the Zagreb-Split motorway was very demanding. In total, 292 various structures (bridges, viaducts, tunnels, overpasses and underpasses) were constructed, and they make a high percentage of 18.6% of the total motorway length, which is 380 km. 26 million m^3 of material were excavated and 30 million m^3 of material were overlain during the construction. The total cost of this motorway was over 3 billion US dollars.

Figure 4. Motorways in Croatia (a part of A1, A5, A7, A10 and A11 are planned or under construction); the black line denotes almost fully completed motorways.

There were 49 bridges and viaducts constructed on the Zagreb-Split motorway, and the longest viaduct Drežnik is 2485 m long. Among 13 constructed tunnels, there are two long ones, Mala Kapela, which is 5801 m long, and the tunnel Sveti Rok is 5727 m long.

The Zagreb-Split motorway makes the connection between two essential routes, the one from Maribor in Slovenia to Zagreb and Split, and the other, along the Adriatic coast, from Rijeka to Split and Dubrovnik. When completed in 2008, the Zagreb-Dubrovnik motorway will be 475 km long. With the route from the Slovenian border all the way to Dubrovnik, the route from the Slovenian border to the border of Serbia and Montenegro, and two routes from the Hungarian border to Split and Dubrovnik, the Croatian motorway system will soon connect the West and Central European countries with the Southern Mediterranean ones.

The second important motorway is the one connecting Zagreb and Rijeka. It is 145 km long, and for the time being some parts are still a single-lane way. Out of the 145 km, 67 km are common with the Zagreb-Split motorway. From the juncture of two motorways, up to Rijeka, there are 15 bridges and viaducts, the longest one having 920 m, and 12 tunnels from 257 m to 2141 m long.

The motorway A4 from the Hungarian border to Zagreb is 97 km long. It has 6 bridges and viaducts, and two tunnels. This is a very busy motorway during summer, bringing tourists from Western and Central Europe to the Adriatic coast.

One of the oldest motorways is the partly built one between Zagreb and Belgrade in Serbia. This important route, connecting Ljubljana in Slovenia and Belgrade, through Zagreb, has recently been almost completed up to the Serbian border on the East. The western part, from the Slovenian border to Zagreb has also been recently completed. The total length of this motorway, from Slovenia to Serbia will be 305 km.

Another route, connecting Maribor in Slovenia and Zagreb, has also been almost completed on the Croatian side. The length of this motorway from the Slovenian border to Zagreb will be 60 km.

The so-called Istrian Epsilon (A8 and A9) is at its final stage of construction. The already completed single-lane way is 130 km long. It includes the Ucka tunnel, which is 5062 m long. The eastern part of the Epsilon connects Rijeka and Pula, whereas the western part connects Pula with the Slovenian border.

3.2 *Deep excavations*

An 18 m high anchored diaphragm wall was constructed in downtown Zagreb to secure the construction site for a shopping centre (Szavits-Nossan et al. 1999). This is an example of the use of sophisticated numerical modeling and interactive design in practice.

The diaphragm wall was a cast in place reinforced concrete structure. The completed excavation is shown in Figure 5, and the diaphragm wall in Figure 6.

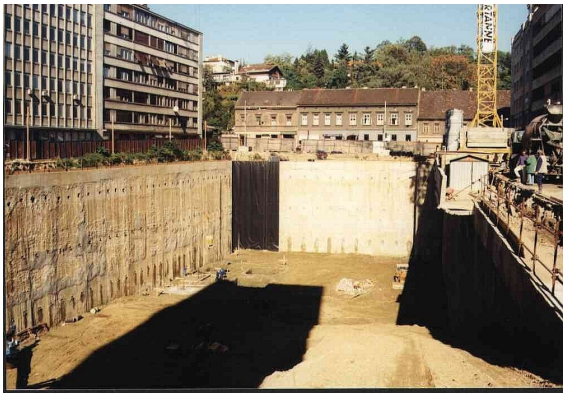

Figure 5. Completed deep excavation in Zagreb (Szavits-Nossan et al. 1999).

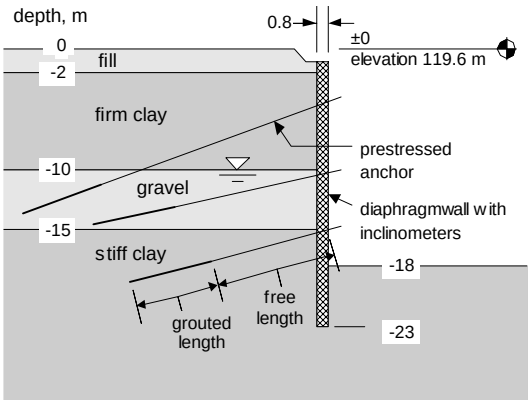

Figure 6. Diaphragm wall cross-section (Szavits-Nossan et al. 1999).

Existing buildings, sensitive to possible ground movements, closely surrounded the construction site. Ground settlements and the anchored wall displacements were monitored by vertical inclinometers embedded into the concrete wall.

Predicted horizontal displacements of the wall, which were obtained by using a special constitutive relationship for soil (Szavits-Nossan et al. 1999), were compared to measured values. Measurements compared surprisingly well to predictions (Figure 7) from the beginning to the end of excavation, so that contingency measures were not used.

Another example of deep excavation, where interactive design was used, is illustrated in Figure 8. This excavation was made in Rijeka in flysh. It was almost vertical and 14 m to 20 m deep (Arbanas et al. 2004). The supporting structure consisted of the reinforced concrete box girder and rock bolts. The results of geotechnical monitoring helped to secure the excavation. The measurements of the rock mass displacements had shown that additional rock bolts had to be installed.

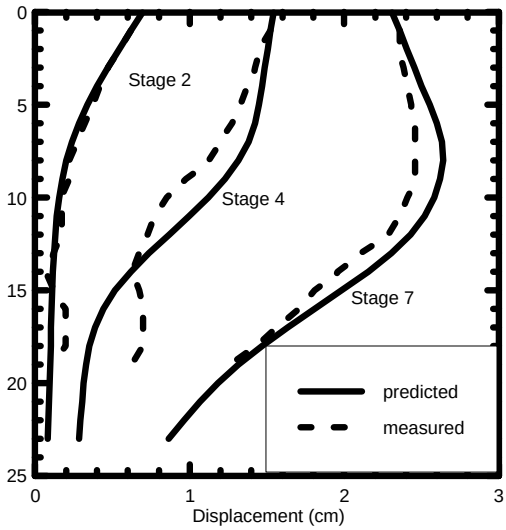

Figure 7. Comparison of predicted and measured displacements of the diaphragm wall (Szavits-Nossan et al. 1999).

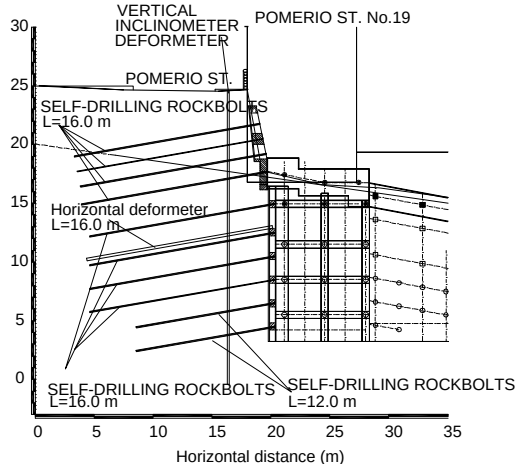

Figure 7. Deep excavation in Rijeka (Arbanas et al. 2004).

4 CONCLUSIONS

The geotechnical education and practice have been going along as a tradition in Croatia, ever since the first geotechnical courses started at the University of Zagreb in 1942. Undergraduate and postgraduate geotechnical courses according to the old curricula have been offered at 6 Faculties within the four Croatian Universities and one Polytechnics. One of the 6 Faculties is the Faculty of Geotechnical Engineering of the University of Zagreb.

In 1993, a new Law on Research and Higher Education started the procedure of restructuring all University and Polytechnics curricula in accordance with the Bologna process. This was a hard and painful procedure, both for the teaching staff and students.

All the 6 Faculties offering geotechnical courses accepted the duration of 3+2+3 for the undergraduate, graduate and postgraduate studies. Their new curricula for the first two cycles have been accredited by the National Agency for Higher Education, and students enrolled the first year of the first cycle in 2005. The Polytechnics in Zagreb is also offering a more practically oriented 3+2 program.

Geotechnical courses are offered in the second cycle for the MSc degree at all 6 Faculties. The Faculty of Civil Engineering in Zagreb also offers the geotechnical specialization in the second cycle. The postgraduate geotechnical program, which has not yet been accredited, is offered at the Faculty of Civil Engineering in Zagreb, and other Faculties include geotechnical courses in their postgraduate proposals.

The continuing geotechnical education for practicing engineers also has a long tradition. Many geotechnical courses have been delivered since 1957.

The geotechnical practice in Croatia is extensive. Many motorways have been constructed in the last decade, and more will be built in the next 5 years, thus making the Croatian motorway system the single most important civil engineering undertaking in Croatia. The 1200 km long motorway system, which will be completed in the next five years, will be connecting the West and Central European countries with the Southern Mediterranean ones. The Zagreb-Split motorway, which has been hoped for within the last thirty years, was the most costly project, and it has been inaugurated in 2005.

Deep excavations in urban areas are always a challenge for geotechnical practice. In Croatia interactive design has been successfully applied for several of these demanding structures, as well as for the motorway tunnels. Extensive monitoring during construction is required for interactive design. When measuring results are combined with sophisticated constitutive models, the comparison of prediction, or back-analyses, and measured values can be very encouraging. This is an illustration of the combined efforts of University professors and practicing engineers in securing successful geotechnical construction.

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