ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 1/2014

SELECTED ASPECTS OF SUSTAINABLE CIVIL ENGINEERING IN RESEARCH WORKS OF PROFESSOR ANDRZEJ AJDUKIEWICZ

Marek WĘGLORZ*

*Dr; Department of Structural Engineering, Faculty of Civil Engineering, Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland
E-mail address: *marek.weglorz@polsl.pl*

Received: 05.01.2014; Revised: 15.03.2014; Accepted: 20.03.2014

Abstract

Professor Andrzej Ajdukiewicz is the well-known and highly appreciated person in the circle of civil engineering in Poland and abroad. There are many examples, that Prof. Ajdukiewicz is hold in high esteem by the academic and engineering community. In the recent period, on March 11th, 2011 Professor Ajdukiewicz was honoured with Doctor Honoris Causa distinction by Technical University in Łódź. In the same year 2011, he received the title and medal of "Personality of Silesian Building Society". In recognition of significant personal contribution to the work of International Federation for Structural Concrete (*fib*) this organization bestowed him Honorary Life Membership in the year 2012. It shall be mentioned, that in the period 2008-2013 Professor Ajdukiewicz was the main editor of the ACEE Journal.

In the recent decade Professor's scientific and professional interests concentrated on selected aspects of sustainable civil engineering, namely: on recycling and utilisation of waste materials in civil engineering, on re-use of the whole structural elements, on durability aspects of concrete structures and on the use of non-metallic reinforcement in concrete elements. The aim of this paper is to remind shortly the scope of each of these topics with references to the recent publications of Prof. Andrzej Ajdukiewicz. These research activities were prepared by Professor together with the team of researchers involved in the research project granted in Poland by the Operation Programme: Innovative Economy (2010-2014).

Streszczenie

Profesor Andrzej Ajdukiewicz jest osobistością dobrze znaną i wysoko cenioną w środowisku budowlanym w Polsce i zagranicą. Można przytoczyć szereg przykładów świadczących o estymie profesora Ajdukiewicza w społeczności akademickiej i wśród inżynierów budownictwa. W ostatnim okresie, 11 marca 2011 profesor Ajdukiewicz został uhonorowany najwyższym wyróżnieniem akademickim: godnością i tytułem Doktora Honoris Causa Politechniki Łódzkiej. W tym samym 2011 roku, został wyróżniony tytułem i medalem „Osobowość Budownictwa Śląskiego". W uznaniu znaczącego wkładu w działania Międzynarodowej Federacji Konstrukcji Betonowych (*fib*) organizacja ta nadała Profesorowi Honorowe Członkostwo w roku 2012. Warto również wspomnieć o tym, że w latach 2008-2013 profesor Ajdukiewicz był głównym redaktorem kwartalnika ACEE.

W ostatnim dziesięcioleciu zainteresowania zawodowe i naukowe profesora Ajdukiewicza dotyczyły głównie wybranych aspektów zrównoważonego rozwoju budownictwa lądowego, a w szczególności: recyklingu i utylizacji odpadów w inżynierii lądowej, ponownego użycia całych elementów konstrukcyjnych, aspektów trwałości konstrukcji betonowych i zastosowania zbrojenia niemetalicznego w elementach betonowych. Celem niniejszego artykułu jest zwięzłe przypomnienie wymienionej tematyki, z przywołaniem aktualnych publikacji profesora Andrzeja Ajdukiewicza. Działania te zostały wykonane przez Profesora Ajdukiewicza w ścisłej współpracy z zespołem naukowców zaangażowanych w projekt badawczy w ramach Programu Operacyjnego Innowacyjna Gospodarka (2010-2014).

Keywords: **Recycled aggregate concrete (RAC); Reuse; Textile reinforced concrete (TRC); Thin-walled prefabricates.**

1. INTRODUCTION

The main areas of professional and scientific activities of Professor Andrzej Ajdukiewicz have been and remain the following:

– analysis, tests and design of reinforced-concrete and prestressed-concrete structures,
– diagnosis and assessment of concrete, steel and timber structures,
– appraisal, inspection, reconstruction and maintenance of structures, especially in the regions of industrial influences and mining subsidence impact,
– application of advanced materials, particularly high-strength/high-performance concrete,
– strengthening of concrete structures, particularly passive and active application of fibre reinforced polymers,
– recycling and utilisation of waste materials in civil engineering,
– durability aspects of concrete structures and non-metallic reinforcement for concrete elements.

This paper will shortly present the scope of the research of Professor Andrzej Ajdukiewicz and his co-researchers, focused on selected aspects of sustainable civil engineering: innovative methods of utilisation of waste materials (recycled aggregate concrete, RAC) and of the whole structural elements (reuse), research of an innovative building materials (textile reinforced concrete composites).

2. STRUCTURAL RECYCLED AGGREGATE CONCRETE: INSTANTANEOUS AND LONG-TERM PROPERTIES (co-author: Alina Kliszczewicz)

The idea of the aggregate's reuse derived from demolition of concrete structures and was put into practice many years ago. In the past, the strength of such aggregates was relatively low; therefore, the applications were of secondary importance. At present, the necessity of demolition of structures with strong, sometimes very strong concrete like building frames, bridge beams or different industrial objects creates the source of rubble aggregate of quite a new generation.

The recent tests have indicated some significant differences in properties of structural recycled aggregate concrete (RAC) and natural aggregate concrete (NAC). Particularly, the relation between compressive strength and tensile/bond strength appeared different in comparison with ordinary concrete of the same grade. Similar differences were recorded in modules of elasticity and in time-dependent properties. These areas have been poorly recognized till now. It was often indicated as a barrier in common introduction of RAC into structural application.

In *fib*-Commission 3, special Task Group 3.10 "Concrete made with recycled materials – life cycle perspective" was created to work on distribution of achievements of structural applications of RAC. Professor Ajdukiewicz and Dr. Kliszczewicz tried to follow some aims considered by this team.

Altogether, 75 beams were tested (57 under short-term load and 18 under long-term load) and in almost the same time 39 columns were tested (21 under short-term load and 18 under long-term load). The range of concretes used in the tests was from 40 MPa to 100 MPa.

In general, the series of members (beams or columns) were made of concrete with three kinds of coarse aggregates (as well recycled as natural): river gravel, mainly quartzite – symbol Q; crushed granite – symbol G; and crushed basalt – symbol B.

To gain recycled aggregates with well-defined properties the RC or PC members were selected. All of them were over 12 years old.

In each series of three members prepared for tests the concrete mixture was very similar, but the composition of aggregate differed according to the various contribution of recycled aggregate: NN – natural – new coarse aggregate and new fine aggregate; RN – recycled coarse aggregate and new fine aggregate; RR – recycled coarse and fine aggregate.

The main data for the mixtures and aggregates are published elsewhere, for example in [5].

In this paper only the long-term tests of beams are presented shortly.

Nine beams in three series were tested for over one year. The dimensions of beams, supports and loading systems were the same for all members. Beams on the test stand loaded with three layers of blocks are shown in Fig. 1.

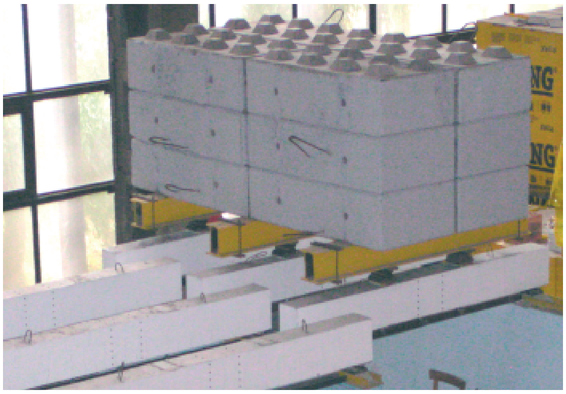

Figure 1.
Beams on the test stand loaded with three layers of blocks

The comparison of deflections during over one year under load and during 3 months after unloading is presented in Fig. 2. The diagrams show the development of deflection for 9 beams made with different kind of aggregate and with different contribution of recycled aggregate.

The load carrying capacity of beams did not show the significant influence of the replacing natural (new) aggregate by recycled aggregate.

However, the considerable increment of deformations in members made of recycled aggregate concrete was recorded. It was stated that the values of deformation depended significantly on the kind of aggregate (river gravel, granite and basalt). This influence was evident for elements with moderate strength concrete as well as for elements with high strength concrete.

Tests' results showed the significant influence of such aggregates on the increase of deformation of elements under loading. Therefore, before responsible application of recycled aggregate concrete some basic properties should be determined. The importance of time-dependent properties, i.e. shrinkage

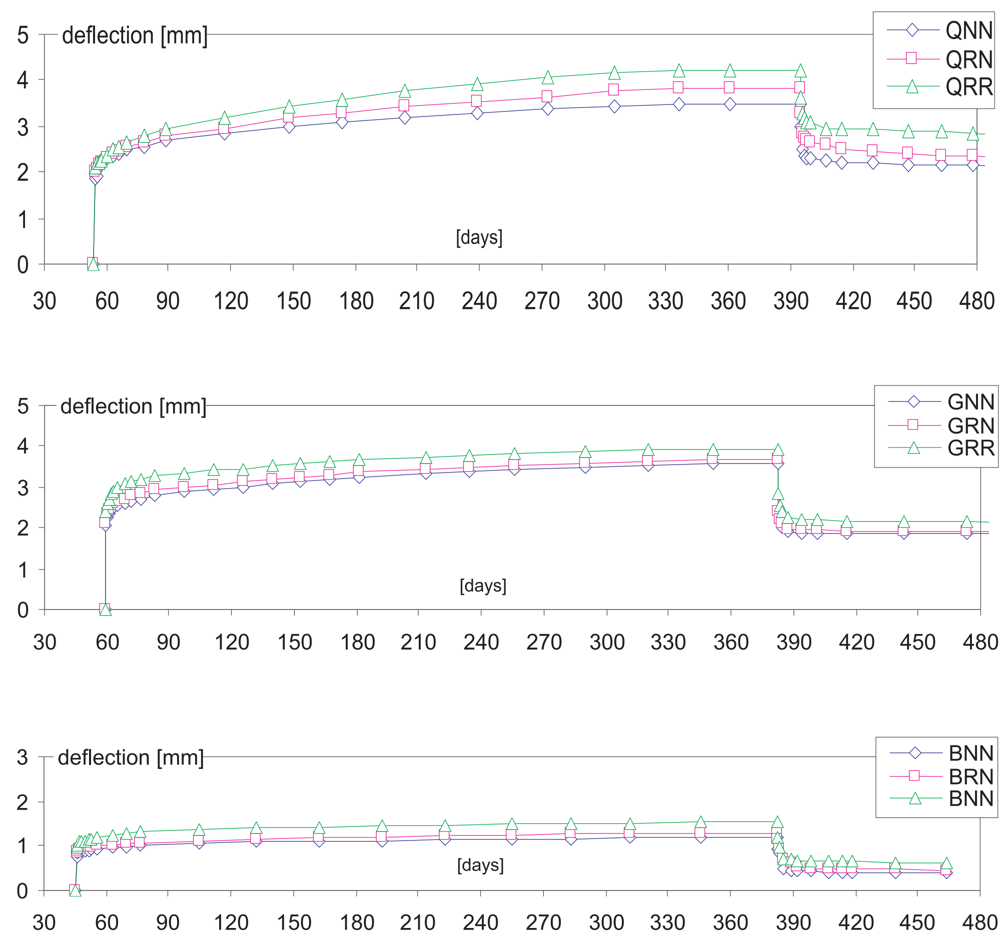

Figure 2.
Results of long-term tests of beams with different contribution of recycled aggregate

and creep, should be emphasized, especially when displacements of beams or deformations of columns could not be neglected.

In general, the recycled aggregates carefully taken from crushed original concrete members of good quality can be commonly used in structures. Some special precautions should be taken in cases of structures particularly sensitive to deformations.

3. REUSE OF RC AND PC PRECAST MEMBERS AS CONTRIBUTION TO SUSTAINABLE CONSTRUCTION (co-authors: J. Brol and Sz. Dawczyński)

Reuse of RC and PC precast structural elements become more and more popular for environmental and economic reasons. Such elements are relatively easy to dismantle and relocate into another structure. Unfortunately, there are no reliable, complex procedures of dismantling, testing and usability assessment of the members which are intended for reuse. The idea of reuse of structural elements has become popular for steel and timber members rather than for concrete members. For both environmental and economic reasons the necessity of such actions has arisen due to many concrete structures disassembling all over the world (Da Rocha; Sattler, 2009). It seems to be particularly significant the common reuse of precast elements, reinforced concrete and prestressed (pre-tensioned) concrete prefabricates alike. Such elements are relatively easy to dismantle and to take away for next use. Apart from dismantling of old structures and partial reuse of elements, in some countries the idea is developed for the design of new structures taking into consideration the future reuse of elements. This is an important contribution to "environmental design" (*fib* Bulletin 47, 2008), being significant part of the sustainable construction strategy (*fib* Bulletin 67, 2012).

The subjects of testing were the two SB-I-80/12 girders originating from disassembled hall of prefabricated construction, 40 years old. Identification of the girders type was based on the inventory of its shape and reinforcement. Actual length of the beams was 11.96 m. According to the catalogue the elements were made of concrete corresponding to present class C35/45; they were reinforced with ordinary steel and tensioned with the use of 39 straight 7Ø2.5 mm strands made of prestressing steel Y1860S7.

Girders singled out for testing were in good technical condition, with no evident defects or cracks and they were obtained from the structure in such a condition. Only the tie-reinforcement (stirrups) was damaged during removal of ribbed plates and concrete levelling layer. The near-surface layers of carbonated concrete in girders were equal to 6÷10 mm.

During loading, as a result of collapse, one girder was damaged. Numerous malfunctions and cracks have appeared. Despite of damage, the girder has been used for testing, but first some repairs with the use of epoxy resin cracks injection were done.

The tests of girders were carried out with the supports spacing equal to 11.25 m (Fig. 3).

Figure 3.
SB-I-80/12 girder on the test stand, during the test

First sloping cracks in the support area appeared at the shear force equal approximately to $F_1 = 150$ kN, and the load carrying capacity exceeded $F_1 = 200$ kN.

Assuming that girders concrete was C30/37, defined by means of the sclerometer and specimens testing, load carrying capacity has been determined (due to the use of compression zone load carrying capacity) corresponding to the loading with two forces equal to $F = 280$ kN each and deflection at the level of 80 mm.

Analysis of girders test results, as well as analytical calculations (with substantial simplifications) show that the girder has got strength comparable to the theoretical one.

Based on the performed PC-beams tests, despite their former long service period (ca. 40 years) it has been stated that they could still be used in other structures instead of being crushed. Usability of elements regained in such a way for reuse should be confirmed by site investigations and some basic laboratory tests. The range of tests depends on the state of recovered members and conditions in which they were used.

No doubt that many of structural members, particu-

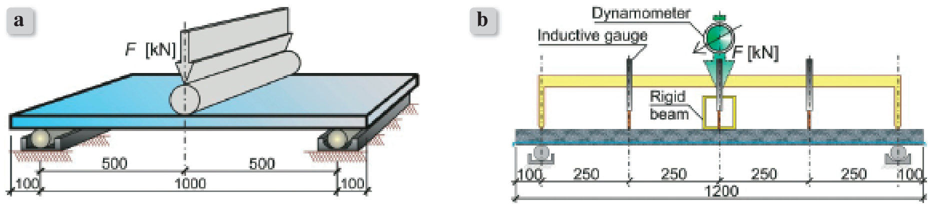

Figure 4.
Test scheme: a) static scheme, b) test stand. Dimensions in [mm]

larly precast RC and PC elements, obtained from properly disassembled structures may be reused. This procedure is reasonable from ecological and economical points of view. Therefore, future reuse should be considered at design stage today.

4. TEXTILE FABRICS USED AS REINFORCEMENT OF THIN-WALLED CONCRETE PLATES (co-authors: B. Kotala, M. Węglorz)

Textile reinforced concrete (TRC) is an innovative, composite building material which comprises of special, fine-grained high quality concrete matrix (alternatively, it can be as well mineral-polymer matrix) and non-metallic (e.g. alkali-resistant glass, carbon, and others) textile reinforcement. Due to chemically-resistant nature of non-metallic fibre materials, the concrete cover is no longer needed as chemical protection. High corrosion resistance of non-metallic fibres and low self-weight of textile fabrics allow to produce lightweight, thin-walled, precast elements. Additional benefit from application of textile fabrics as reinforcement, particularly those multidirectional, is the possibility to align the yarns in the direction of expected tensile stresses, leading to an increase of their effectiveness and load-carrying capacity.

In comparison with ordinary steel, non-metallic fibres are described by low deformability, which also characterizes concrete matrix. After transformation into composite – TRC is characterized by linear-plastic behaviour with strain hardening.

Taking advantage of the experience gained by German experts (Curbach et al.), this still relatively new concept is being scientifically researched also in the Structural Engineering Department of the Silesian University of Technology, Gliwice (Ajdukiewicz et al., 2009). Apart from laboratory tests, similarly to German examples, fields of future applications in building industry are being investigated. The new opportunities for further research were revealed with the financial support of the research by EU as well as with availability of the new textile fabrics (made of carbon) in the Polish market.

The tests were made of thin precast plates – like façade panels, elements of road screens, and other members exposed to severe conditions – made with ASCC mixtures and reinforced with different kinds of fabrics made from AR-glass, PVA (poly-vinyl-alcohol) and carbon fibres. The tests series of similar elements were done to make comparison with elements reinforced with ordinary steel fabrics (Series-05). The results showed the important role of cement grout penetration into the yarn creating fabrics.

The flexural behaviour has been examined on fifteen concrete plates, with dimensions 1200×1000 mm in plane and only 40 mm in depth. In the research programme the plates were divided into five series due to the kind and the type of reinforcement.

The elements were reinforced with flat, orthogonal fabrics, cast with ensuring the minimal concrete cover of 10 mm (no durability requirement).

Elements were subjected to static instantaneous load up to the failure (Fig. 4).

At first, all the plates performed linear behaviour before cracking. Afterwards, in post-cracking phase, the differences between elements appeared.

Load-carrying capacities of the plates differed in accordance with reinforcing material, due to distinctions in fabrics' tensile strengths. The tests proved high quality of AR-glass and higher strength carbon textile fabrics (Series-01 and -04) as reinforcement. For both: PVA (Series-02) and low strength carbon fibre textile fabrics (Series-03), sudden drop in load-carrying capacity was observed after cracking. Afterwards, the plates performed large deflections at failure. This post-cracking behaviour of the plates is important when taking into consideration specific structural elements (e.g. road-screens), but for most practical applications the first peaks of diagrams are important, according to those presented in Fig. 5.

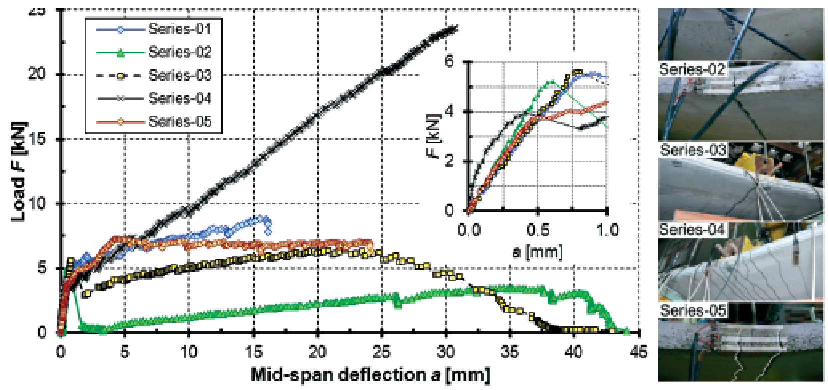

Figure 5.
Test results: F-a plot and failure modes

5. INSTEAD OF CONCLUSIONS

In this publication, I would like to wish all the very best to Professor Andrzej Ajdukiewicz on his 75-years birthday! Although, for Polish professors, age of 70 formally means retirement from the academic career, the engineering and academic community in Poland and abroad has still been appreciating a lot of hard work and energy of Prof. Ajdukiewicz. It is not surprising that much for a person who is the great successor of Prof. Stefan Kaufmann - the active engineer and academic until almost his 100 years of age. I wish that now and in the future Professor Ajdukiewicz would still keep on taking from his predecessor great example of engineering and academic longevity!

REFERENCES

[1] *Ajdukiewicz A., Kliszczewicz A.*; Influence of recycled aggregates on mechanical properties of HS/HPC. Cement & Concrete Composites, Vol.24, No.2, 2002; p.269-279

[2] *Ajdukiewicz A., Kliszczewicz A.*; Structural Recycled Aggregate Concrete; Instantaneous and Long-term Properties. Proceedings of the fib Symposium “Concrete Structures for Sustainable Community”, Royal Institute of Technology (KTH) – Swedish Concrete Association, Stockholm, June 11-14, 2012; p.67-70

[3] *Ajdukiewicz A., Kliszczewicz A.*; Comparative Tests of Beams and Columns Made of Recycled Aggregate Concrete and Natural Aggregate Concrete. Advanced Concrete Technology (Japan), Vol.5, No.2, 2007; p.259-273

[4] *Ajdukiewicz A., Kliszczewicz A.*; Early Age Shrinkage of Natural and Recycled Aggregate Concrete. Proceedings of the 7th International Conference on “Concrete under Severe Conditions – Environment & Loading” 23-25 September, Nanjing, China; RILEM Publications: Vol.1, 2013; p.560-571

[5] *Ajdukiewicz A., Kliszczewicz A.*; Differences in Behaviour of Natural- and Recycled-Aggregate Concrete Members. The Fourth International fib Congress 2014, Mumbai “Improving Performance of Concrete Structures”, Proceedings Universities Press (India), Hyderabad, Summary Papers, Vol.1, 2014; p.282–285, Full Papers CD – p.801-811

[6] *Ajdukiewicz A.,Brol J., Dawczyński Sz., Adamczyk K.*; Reuse of RC and PC precast members as contribution to sustainable construction. Proceedings of fib Tel-Aviv 2013 Symposium “Engineering a Concrete Future: Technology, Modelling and Construction”, 22-24 April, 2013; IACIE and Technion – Israel Institute of Technology, Tel Aviv, 2013; p.483-486

[7] *Ajdukiewicz A., Brol J., Dawczyński Sz.*; Reuse of reinforced-concrete precast roof slabs. Proceedings of the 9th Central European Congress on Concrete Engineering – CCC'13 "Concrete Structures in Urban Areas", 4-6 September, 2013 Wrocław, p.272-275

[8] *Ajdukiewicz A., Weglorz. M., Kotala B.*; Application of non-metallic fabrics as reinforcement in thin-walled precast concrete members. ACEE Journal, No.2, Vol.2, 2009; p.57-66

[9] *Ajdukiewicz A., Kliszczewicz A., Weglorz. M., Kotala B.*; Thin-Walled Textile Reinforced Concrete Precast Members with Almost-Self Compacting Concrete. Proceedings of fib Tel-Aviv 2013 Symposium "Engineering a Concrete Future: Technology, Modelling and Construction", 22-24 April, IACIE and Technion – Israel Institute of Technology, Tel Aviv, 2013; p.479-482

[10] *Ajdukiewicz A., Weglorz. M., Kotala B.*; Behaviour of precast concrete plates reinforced with textile fabrics under short-term and long-term loading. Proceedings of the 9th Central European Congress on Concrete Engineering – CCC'13 "Concrete Structures in Urban Areas", 4-6 September, Wrocław, 2013; p.276-279

[11] *Ajdukiewicz A.*; The place of concrete in sustainable civil engineering in Poland. Beton- und Stahlbetonbau, Vol.100, Heft 7, 2005; p.633-641

[12] *Ajdukiewicz A.*; On durability aspects of concrete members. Arab Construction World (Lebanon), No.7, Vol.XXVI, 2008, p.22-24

[13] *Ajdukiewicz A.*; "Green concrete" in structures; Part 1. Material and technological aspects; Part 2: Design aspects and examples. Materiały Budowlane, No.12, 2012; p.3-6, No. 1, 2013; p.76-79 (in Polish)

As a member of *fib*-Commission 3. "Environmental aspects of design and construction", Prof. Ajdukiewicz was directly involved in the preparation of *fib* Bulletins considering problems of environmental impact and sustainability of concrete structures:

fib-Bulletin 28: Environmental Design. State-of-art report. February 2004

fib-Bulletin 71: Integrated Life Cycle Assessment of Concrete Structures. State-of-art report. December 2013