Adaptation of the Infrastructure to Climate Change – Research Needs

Johan Silfwerbrand[1]

[1] KTH Royal Institute of Technology, Dept. of Civ. & Arch. Engrg,, Stockholm, Sweden
jsilfwer@kth.se

Abstract. Despite the Paris Agreement and numerous actions, climate change seems to be inevitable. Events and phenomena as forest fires, hurricanes, floods, and melting glaciers can hardly be explained solely by natural changes in the weather. We need to do our very best to limit the climate change, but also a thermal increase below 1.5°C affects our planet. Up to now, most research has been devoted to mitigation, how can we reduce and preferably prevent the climate change. This is particularly valid for the concrete research that in recent years has been dominated by making the concrete material more environmentally friendly or greener by replacing parts of the Portland cement with industrial by-products, e.g., fly ash, ground-granulated blast-furnace slag and silica fume. However, in order to protect our built environment for higher sea levels, greater floods, forest fires close to urban areas, and possible increased wind loads, measures to protect our built environment, not least our infrastructure are urgent. The years 2030, 2040 and 2045, which frequently are mentioned in the environmental agreements, are coming closer. Concrete has a large role to play both in protecting structures such as barriers around cities close to the sea or rivers and for strengthened existing or new structures that can withstand increased loads and attacks from water, moisture, wind, and fire. The paper describes and discusses research needs focusing on Scandinavian conditions identified in an ongoing pilot study.

Keywords: Adaptation, Climate change, Concrete structures, Infrastructure, Pilot study, Research needs.

1 Introduction

1.1 Climate Change

Since the start of the industrialization, the CO_2 content in the atmosphere has increased from 280 to 420 ppm. The global temperature has increased and the vast majority of the climate researchers is convinced that the temperature rise is caused by human activities. Despite intensive international initiatives, agreements and measures, the 1.5°C temperature increase goal seems to be difficult to reach. Also such an increase will have – and already has – an obvious impact on the Globe. The impact reaches also different levels since the temperature increase is not even in all parts of the earth and certain countries – islands in the Atlantic and Pacific Oceans constitute one example – are more vulnerable than other ones. Examples of effects of the climate change are rising sea levels, hurricanes, floods, droughts and forest fires.

Both research and measures to deal with climate change can be divided in mitigation and adaptation (**Fig. 1**). In research, a vast majority of the recent projects dealing climate change have been focusing on how to mitigate climate change. Since a couple of years, Swedish coastal municipalities, among many others, have started to plan for the adaptation to climate change. Connected to this is an obvious need of research. This will be discussed in this paper.

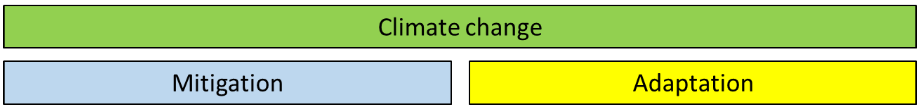

Fig. 1. Measures against climate change are divided in mitigation and adaptation.

1.2 Concrete and Climate Change

Concrete is the most common manmade construction material around the world. The necessary constituents are fairly cheep and available in most parts of the world. The problem is the large CO_2 emissions connected to the cement production. It stands for 5-8 percent of the global CO_2 emissions. During the last 20 years, research and development at both cement producers and universities in a large number of countries have been devoted to various measures to reduce these emissions. The main tools are more efficient cement kilns, use of alternative fuels in the kiln and replacement of part of the cement with Supplementary Cementitious Materials (SCM), e.g., fly ash, slag, silica fume and limestone filler. By using these measures, it has been possible to reduce the CO_2 emissions from the cement from approximately 1000 kg CO_2 per metric ton cement to 650 kg/ton. In both Norway and Sweden, the cement producers are planning to install systems for Carbon Capture Storage (CCS) on their main cement plants. Carbon Capture Use (CCU) would be an even better solution since it would not be dependent on a long-term storage under the sea bed of the North Sea.

Durability is connected to sustainability and research on the durability of concrete has been conducted for more than 60 years. By making the reinforced concrete structures more durable they do neither need repair nor replacement prematurely. A prolonged service life distributes the CO_2 emissions over a longer time and postpones the need of new natural resources. Climate and weather conditions in the Nordic countries are severe and this is likely the reason why the Nordic concrete research on durability has been strong.

Decreasing the CO_2 emissions from the cement and concrete production and prolonging the service life are not the sole measures to mitigate climate change. **Fig.** 2 tries to identify the most important ones also including positive effects during the service life and reuse and replacement [1, 2].

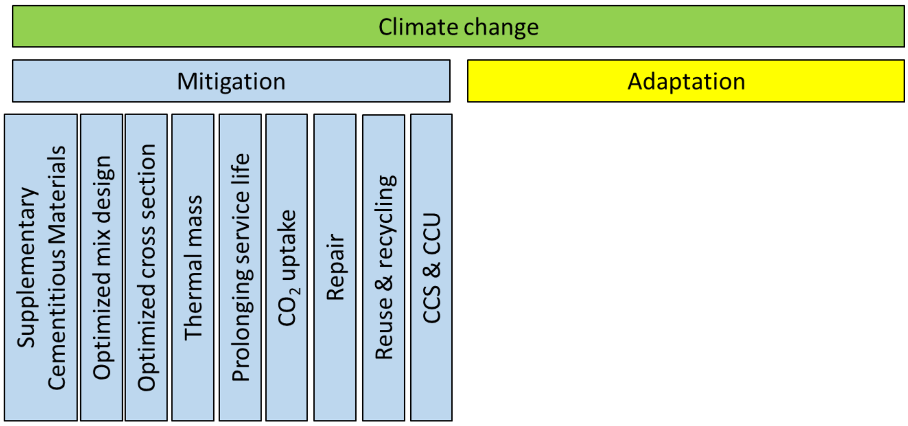

Fig. 2. In the concrete area, there is a large number of measures to mitigate climate change [1, 2].

1.3 Limitation

This paper is limited to Swedish conditions and Swedish research. However, most of the research projects identified are dealing with general aspects of adaptation to climate change. Consequently, the paper and its conclusions are considered to be interesting for international readers.

2 Adaptation to Climate Change

2.1 Introduction

A survey on on-going Swedish research on adaptation focusing on concrete and the infrastructure has been conducted. An early observation is that both researchers and civil servants (e.g., at the Swedish Transport Administration) include a large number of different measures in the term adaptation to climate change. Everything between inventory of consequences to physical measures such as strengthening existing structures and moving vulnerable structures to safe ground (**Fig. 3**).

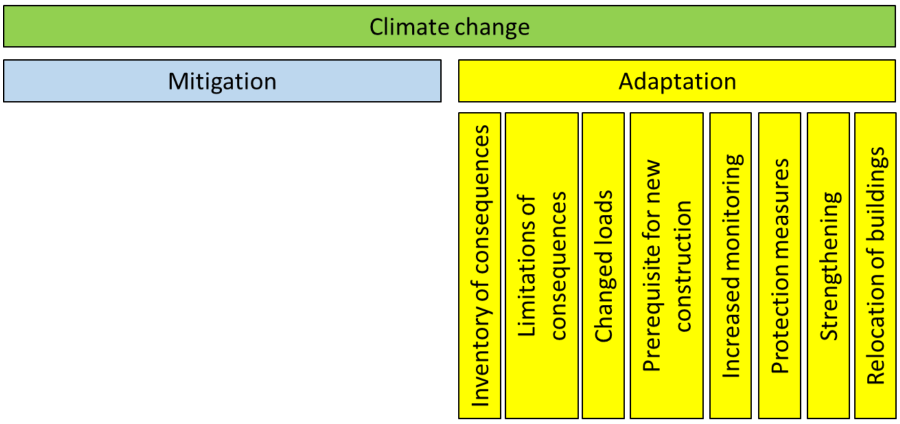

Fig. 3. Examples of various measures to adapt the built environment to climate change.

2.2 The Swedish Transport Administration

The Swedish Transport Administration has been working with adaptation to climate change since 2012. Four years later the agency had developed a plan of action. It can be summarized in three bullet points:

1. Create prerequisites for an efficient work with adaptation to climate change.
2. Prevent the negative consequences due to climate action by creating robust civil engineering structures.
3. Handle effects of climate actions.

Table 1. Anticipated climate changes and their impact on the transport infrastructure [3].

Climate change	Impact on the transport infrastructure
Sea level rise	• Sea water flows into tunnels. • Islands are disconnected from the mainland. • Road & railway sections are flooded. • Ferry-boats cannot make land to ferry berth
Ground water table change	• The soil stability can be weakened & damage the foundation.
Heavy precipitation & large flows	• The risk of scour, material removal, flood, earth fall & landslide increases. • Mud streams may block culverts that in turn may lead to

	flushing road & railway sections away. • Tunnels are vulnerable if drainage systems and pumps cannot handle large water flows.
Increased average temperature	• The evaporation increases causing more precipitation. • The ground frost period is shortened leading to problems for the forest industry & its access to roads with high load-carrying capacity during the winter. • More zero temperature passages that may give pavement damages & increased risk of slippery. • Increased use of de-icing salt in northern parts of Sweden. • The ice roads in north Sweden disappear.
Heat waves & drought	• The rutting on asphalt roads increases. • Risk of moisture, mould and corrosion increases. • Risk of heat distortions & railway switches increase. • The vegetation close to the roads is effected. • The working environment for road construction work etc. is impaired due to high temperature.
Forest fire	• Traffic on roads close to forest fires may be stopped.

2.3 Swedish National Board of Housing, Building and Planning

Swedish National Board of Housing, Building and Planning (*Boverket* in Swedish) co-ordinates the Swedish national work with adaptation to climate change. It has published a number of guidelines on climate risks in general planning, cultural heritage at climate change, ecosystem duties in the built environment, water supply, green planning, and accidents in the nature. In the area of civil and architectural engineering, Swedish National Board of Housing, Building and Planning is working with the development of new design loads for snow and wind. The predictions of wind load changes are difficult to make. The snow loads seem to increase (at least initially) in Norway and along the mountain chain Skanderna between Norway and Sweden (**Fig. 4**). For more extreme scenarios, the snow loads will successively decrease [4].

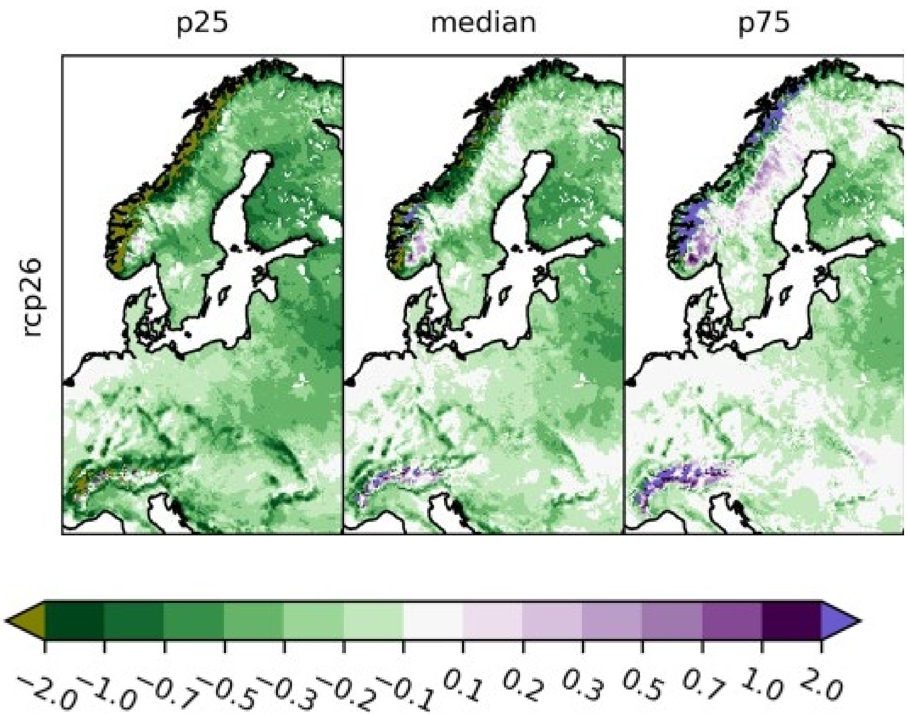

Fig. 4. Change in snow load (in kN/m^2) between the periods 1970–2019 and 2030–2079, for climate scenarios RCP 2.6 (the scenario "low emissions", approximately a global temperature rise of 1°C to year 2100). The centre column shows the ensemble median, while the left and right columns show the 25th (left) and 75th (right) percentiles. From [4].

2.4 Lund University

Lund University, the second oldest university in Sweden, located in the south, is leading the Swedish research on adapting the infrastructure to climate change. During the latest five years, a group of researchers has conducted a couple of research projects in this area. The research results have been summarized in a report [5]. In an important part of the report, 31 different risks are identified. These are divided into seven groups:

1. Durability
2. Performance
3. Geotechnics
4. Increased loading
5. Accident loads
6. Extreme natural events

7. Maintenance

Some examples of the 31 identified risks are accelerated deterioration (durability), long-term deformation (performance), increased sour (geo-technics), increased wind loads (loading), ship collisions (accident loads), flood (extreme natural events), and increased risk of electronic energy shortages (maintenance).

The report provides suggestions for measures against 28 of the 31 identified risks. The authors have not categorized these measures but they could have done that. Examples are changed loads, measures to limit the consequences, prerequisite at new construction, increased monitoring of existing structures, protecting measures, strengthening, and relocation of buildings or bridges. The field of adaptation to climate change is very wide, cf. **Fig.** 3.

The research at Lund University has also led to a PhD Thesis. In December 2022, Amro Nasr defended his thesis entitled “Risk Assessment of Climate Change Impacts on Built Infrastructure” [6]. The thesis consists of eight scientific papers and an 84 pages long extended summary including almost 300 references. The content is disparate and some of the papers are more closely connected to consequences of climate change than adaptation to climate change.

In one interesting paper [7], Nasr develops a decision basis for bridge managers. He thinks that the risk contains four components: (i) hazard, (ii) impact, (iii) vulnerability, and (iv) consequences. These are combined to an index that can be used for rank and prioritize different risks, different bridges, different bridge stocks, and different measures to climate changes and the effects these measures may lead to.

Nasr’s thesis also contains four papers in which he analyses the impact of climate changes on four different deterioration and failure mechanisms:

- Chloride-induced reinforcement corrosion in concrete structures [8].
- Fungal decay of timber elements [9].
- Creep of concrete structures [10].
- Local scour under bridge piers [11].

Nasr’s last paper [12] has the subheading “challenges and research needs” and provides some ideas for research needs. They are all connected to design of new structures considering climate change. More research is needed to identify the risks that need to be considered in the design.

Another researcher at Lund University, Professor Magnus Larson, and his research group at the Div. of Water Resources Engineering has recently received research money for the following new research projects:

1. Societal impact along the Swedish south coast due to increased scour from rising sea levels.
2. Adapting roads and railroads to climate change in areas close to the shore.
3. Impact of extreme river flows on bridges with special focus on local scour.
4. Crowd sourcing of data for improved handling of urban flood risks.
5. StormMan – A synthesis of governance structures and policy instruments to overcome economic, environmental and social implementation challenges moving toward sustainable storm-water management.

6. EnhanCing hydrODIVERsity for improving catchment based climate resilience (EcoDiver).

These research projects have just started so there are no available results or conclusions yet. However, it shows the strong position that Lund University has within the Swedish research on adaptation to climate change.

2.5 KTH Royal Institute of Technology

KTH (located in the Swedish capital Stockholm) is the largest and oldest technical university in Sweden. Sustainability is one of four keywords for its entire business. The other three are digitalization, internationalization, and (gender) equality. In 2021, KTH established a new centre; Climate Action Centre. This centre is wide and multidisciplinary and covers KTH's wide research field from natural science and technology to social sciences. The vast majority of research projects within the centre deals with mitigation but a few deals with adaptation to climate change. They could all be classified as "inventory of consequences" (see **Fig**. 3).

There are, of course, numerous KTH projects dealing with sustainability additional to those included in Climate Action Centre. However, Climate Action Centre is the first attempt to highlight not only mitigation but also adaptation. Research towards bridges and other civil engineering structures are mainly run at the Dept. of Civil & Architectural Engineering. A recent survey showed that almost all of the Department's ongoing research projects included sustainability and mitigation but hardly any adaptation to climate change. The pilot study, that here is described, is an exception.

2.6 Other Swedish Research Initiatives

In civil engineering, there are four major Swedish technical universities. Above, Lund University and KTH are mentioned. The other two are Chalmers in Göteborg in the west of Sweden and Luleå Technical University in the north. Both of them have many ongoing projects related to concrete and sustainability but none devoted to adaptation to climate change.

RISE – Research Institutes of Sweden – is the major Swedish research institute. It has led a couple of research projects devoted to "blue-grey-green" system solutions for urban areas. Blue relates to water, grey to concrete and other hardened surfaces, and green to vegetation. Increased precipitation and rising sea levels are probably the most severe effects of climate changes in Sweden and other countries with temperate climate. The risk of flood increases. The "blue-grey-green" system is one solution to the problem of flood in cities. The systems deal with different measures to let the excess of water flew to the ground-water through permeable pavements and green areas and not flood the storm-water system. Concrete has an important role here. It is possible to make both permeable cast-in-place concrete pavements and permeable concrete block pavements. **Fig. 5** shows one example, here with permeable asphalt. However, permeable concrete works at least as well.

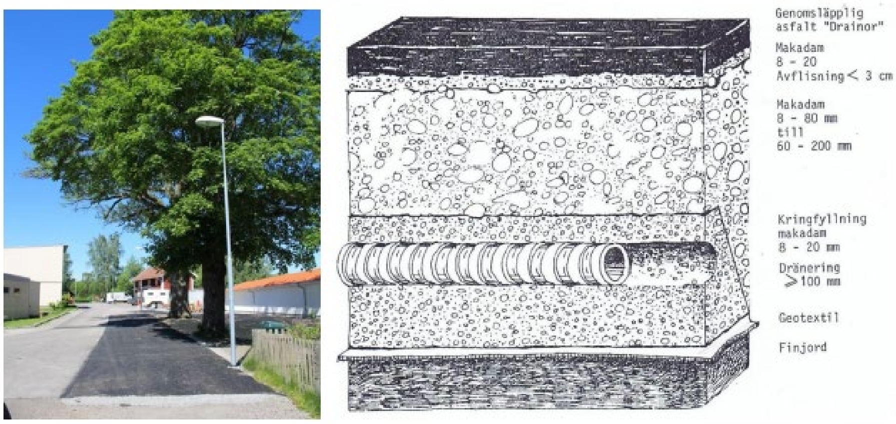

Fig. 4. System solution for the storm-water handling at Lilla Vallen in the Swedish city Växjö. The pavement system next to the trees consists of a permeable asphalt resting of two layers of crushed gravel, a geotextile and fine soil [13].

3 Research Needs

Based on the investigation summarized above, the following research needs concerning concrete structures and adaptation to climate change have been identified.

- Development of new design loads for wind and snow that are based on anticipated changes due to climate change and not based on statistics from a period before the start of the climate change.
- Development of efficient and possibly industrialized methods to strengthen existing structures for the anticipated effects of climate change.
- Efficient concrete barriers protecting built environment close to the shore from rising sea levels. “Efficient” means that the CO_2 footprint for cement and concrete used for the barrier must be much less compared to the CO_2 emissions saved by maintaining these buildings and other structures than demolishing them and build new ones on “safe” ground.
- Continuing of the promising research on “blue-grey-green” systems for protecting urban areas for floods.
- Development of refined concrete pipes for waste water and storm water systems replacing up to 150 years old ones designed for much less flews.
- Investing the effects of climate change, e.g., increased temperature, increased relative humidity, increased fire risks, and possible increased wind loads on concrete’s competitiveness in comparison with other construction materials such as timber and asphalt.

- Adapting the production of concrete structures to climate changes taking advantage of shorter winters with less risk of frost damages but considering increased risk of thermal cracks during longer and hotter summers.

4 Concluding Remarks

Climate changes are impossible to stop but all efforts have to be done to limit the global temperature rise as small as possible. During the latest 10-20 years, the concrete research has to a high percentage been devoted to mitigation, where durability and use of Supplementary Cementitious Materials are important subareas. However, climate changes are already here and they will be larger before the temperature rise is stopped. It is urgent to protect the built environment for negative effects of the climate changes, e.g., rising sea levels, floods, and fires. This paper summarizes current Swedish research activities in the field of adaptation to climate change. A list of research needs have been identified and they are listed in the end of the paper.

References

1. Silfwerbrand J (2012) The Effect of Climate Changes on Concrete, Concrete Structures, and Concrete Construction. Proceedings, fib Symposium on "Concrete Structures for Sustainable Community", Stockholm, Sweden, June 11-14, 2012: 553-556.
2. Silfwerbrand J (2020) Concrete and Sustainability – Some Thoughts from a Swedish Horizon. Nordic Concrete Research 63: 79-87.
3. Swedish Transport Administration (2018) Regeringsuppdrag om Trafikverkets klimatanpassningsarbete. (Governmental commission on Swedish Transport Administration's climate adaptation work). Report 2018:195, Borlänge, Sweden. (In Swedish).
4. Larsson Ivanov O, Bärring L, Wilcke R A I (2022) Climate change impact on snow loads in northern Europe. Structural Safety 97.
5. Nasr A, Larsson Ivanov O, Björnsson I, Honfi D, Johansson J, Kjellström E (2019) Klimatförändringars inverkan på broars säkerhet och prestanda: En översyn av potentiella effekter och anpassningsåtgärder. (Influence of climate changes on the safety and performance of bridges: An overview of potential effects and measures for adaptation). Report TVBK-3072, Lund University, Dept. of Building & Environmental Technology, Div. of Structural Engineering, Lund, Sweden. (In Swedish).
6. Nasr A (2022) Risk Assessment of Climate Change Impacts to Built Infrastructure – Identification, Analysis, and Treatment of Climate Change Risks to Bridges. PhD Thesis, Lund University, Dept. of Building & Environmental Technology, Div. of Structural Engineering, Lund, Sweden.
7. Nasr A, Johansson J, Larsson Ivanov O, Björnsson I, & Honfi D (2022) Risk-based multi-criteria decision analysis method for considering the effects of climate change on bridges. Structure and Infrastructure Engineering, 2022.
8. Nasr A, Honfi D, Larsson Ivanov O (2022) Probabilistic analysis of climate change impact on chloride-induced deterioration of reinforced concrete considering Nordic climate. Journal of Infrastructure Preservation and Resilience, 3 (8).

9. Nasr A, Niklewski J, Björnsson I, & Johansson J (2022) Probabilistic analysis of climate change impact on fungal decay of timber elements in ground contact and their long-term structural performance. Wood Material Science and Engineering.
10. Nasr A (2022) Probabilistic analysis of the impact of climate change on creep of concrete structures in Sweden. Structure and Infrastructure Engineering.
11. Nasr A, Björnsson I, Johansson J (2022) National level analysis of the impact of climate change on local scour under bridge piers in Sweden". Journal of Infrastructure Systems (submitted).
12. Nasr, Larsson Ivanov O, Björnsson I, Johansson J, Honfi D (2021) Towards a conceptual framework for built infrastructure design in an uncertain climate: challenges and research needs. Sustainability, 13 (21): 11827.
13. Sörelius H, Andersson L, Fransson A-M, Stål Ö, Fridell K, Bodin Sköld H, Boström C, Rosenlund H, Alvem B-M, Embrén B (2017) Klimatsäkrade systemytor för urbana miljöer – referensanläggningar och studier i urban miljö. (Climate secured system areas for urban environments – reference objects and studies in urban environments). Technical report, Vinnova – Utmaningsdriven innovation – Hållbara attraktiva städer (Challenge driven innovation – Sustainable and attractive cities), Stockholm, Sweden. (In Swedish).