

# Sustainability Considerations for Underground Concrete Manholes

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**ABSTRACT:** Sewer systems enclose one of the harshest environments on concrete materials. These systems if made of concrete are usually accessed for maintenance and inspection by precast concrete manholes. The present design practices of these shafts components in Canada are generally conservative which results in heavily reinforced bases. If verified by full scale testing the code allows the use of alternative manhole design. To produce a more sustainable precast concrete manhole the steel reinforcement has to be minimized or even eliminated altogether if possible. In the course of introducing a more sustainable manhole a full scale load testing of non-reinforced base precast concrete manhole in a controlled laboratory environment was performed under critical configurations of the Ontario truck. This was followed by an extensive numerical investigation on the proposed manhole. The results showed that the proposed sustainable manhole can withstands applied loads without cracks in the shaft or its base. After verifying the structural validity of the proposed manhole design the sustainability of this design was evaluated. Also, a life cycle assessment scheme for precast concrete manholes was proposed. And the sustainability efforts in Precast Concrete manholes were summarizes

## 1 INTRODUCTION

One of the most used sustainability definition is that of the World Commission on Environment and Development (1987) which defines it as “*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*”. Another sustainability definition introduced at the 1992 Earth summit in Rio de Janeiro was “*Economic activity that is in harmony with the earth’s ecosystem*” (Bjork, 1999). To evaluate the sustainability of a structure or a system the environment, economic and social aspects should be balancely considered in which is referred to as either the three-pillar framework (Cement Concrete and Aggregates Australia, 2010) or the triple bottom line concept (Cement and Concrete Institute, 2011). All three factors should be analyzed over the full life cycle of the structure by using what is referred to as the life cycle assessment (LCA). There are several systems available to rate the sustainability of a structure such as the LEED system in North America, the Green Star system in Australia, and ESTIDAMA in the United Arab Emirates. In this paper a life cycle assessment (LCA) scheme is proposed for precast concrete sewer and storm water manholes. Then the

sustainability efforts carried on precast concrete manholes are briefly described. Finally, a proposed sustainable precast concrete manhole is introduced and evaluated.

## 2 LIFE CYCLE ASSESSMENT SCHEME FOR PRECAST CONCRETE MANHOLES

In these paragraphs a life cycle assessment scheme for precast concrete manholes is proposed. This scheme divides the life cycle of the manhole into five phases:

1. Materials production
2. Manhole components manufacturing
3. Manhole installation and construction
4. Manhole usage
5. Manhole end of life

The life cycle assessment should be carried out by evaluating the three-pillars of sustainability (environment, economic and social) in each of the five phases. In precast concrete sewer and storm water manholes the “Materials production” stage would cover production of the two main components concrete and steel. When evaluating concrete production the primary source of CO<sub>2</sub> emission is attributed to the production of the cement. In average the produc-

tion of 1kg of Portland clinker emits almost 1 kg of CO<sub>2</sub> to the atmosphere. That is why concrete manufacturers' intend to partially replace Portland cement by residual materials from other industries such as Fly ash and Slag (Nielsen, 2008). The energy consumed and CO<sub>2</sub> emission associated with the steel wires and rebars production depended on their production methods. Sandberg, et.al, (2001), stated that the total CO<sub>2</sub> emission for production of one ton of steel wires and rebars by the electric arc furnace route ranges between 0.15-1.08 ton CO<sub>2</sub>/ton steel with an average value of 0.59 ton CO<sub>2</sub>/ton steel. Usually manhole manufacturers tend to use recycled steel in their manhole components to reduce the CO<sub>2</sub> emission related to its production. On the other hand, both cement and steel production are labor intensive industries and contribute strongly to the local jobs. Also, the CO<sub>2</sub> emission associated with the transportation of the manufactured cement, steel and other raw materials used in the manhole production from their production - or home locations - to the manhole manufacturing factory should be accounted for in the life cycle analysis. The values due to transportation vary depending on the transport distance and method.

The amount of CO<sub>2</sub> emission associated with the manhole components manufacturing depends on the type of casting: wet or dry. Usually the wet casting requires less energy to vibrate and agitate the concrete as well as it does not require steam curing. The exact amount of CO<sub>2</sub> emission varies from one company to another depends on the advances in the used equipments. In this stage also the CO<sub>2</sub> emission due to transportation from the factory to the installation site should be accounted for. Usually, precast concrete manholes come ready to install and do not require any on-site casting except for the benching if it is not a pre-benched manhole. This results in a time and effort-efficient installation, and causes minimum disturbance to the construction site. Precast concrete manholes have an expected life span of 100 years due to its durability, fire resistance and strength characteristics. It is expected that - in the usage stage of the manhole - the disturbance to the whole sewer or storm water systems due to maintenance or replacement needs of the manhole would be less than that for other manhole types. Usually the life cycle cost for projects using concrete as their major construction material is lower due to its durability. At the end of the life of the precast concrete manhole its materials (concrete and steel) are fully recyclable and can be reused.

### 3 SUSTAINABILITY EFFORTS IN PRECAST CONCRETE MANHOLES

Manholes are the main access points to the sewer and storm water systems for checking and maintenance. The fact that the codes governing the sewer and storm water systems require the presence of a manhole at each junction, change in grade, change in direction of the system and at certain maximum distances along the pipe lines (Ministry of Municipal Affairs and Housing (MMAH), (2006), illustrates the importance of manholes as a component of these systems. In this paper the discussion concentrates on precast concrete manholes which are very strong when installed in the ground. Some of the advantages of these types of manholes over other types are that they don't rust; burn or rot and they have a service life exceeding 100 years if properly designed. Based on the National Precast Concrete Association (NPCA) (2010) precast concrete manholes can help in earning the infrastructure project LEED points as described in the following table.

The sustainability efforts regarding manholes are part of the efforts of increasing the sustainability of the whole sewer or storm water systems. These efforts can be grouped into three main areas: the manhole's concrete mix design, the manhole's casting and production procedures and the treatment of the manhole's surface. Following are some of the efforts documented in the literature in each of these three areas.

#### *3.1 The manhole's concrete mix design*

Altering the concrete mix design to increase the sustainability of the precast concrete manhole can be done to achieve three main goals. The first is to reduce the amount of cement –which has a high CO<sub>2</sub> emission associated with its manufacturing- used in the mix and replace it with materials that have less CO<sub>2</sub> emission related to its manufacturing. The second is to alter the concrete mix design by adding additives and/or admixtures to enhance the durability performance of the manhole. This, in its turn, will increase the service life of the structure, reduce the required maintenance and replacements, and lead to a more sustainable manhole. The third is to produce lighter weight manholes which will reduce the energy and CO<sub>2</sub> emissions associated with the transportation and installation of these manholes. The ultimate aim of the efforts done on altering the mix design is to achieve the three goals if applicable. Some of the

Table 1: Proposed LEED points to be gained as proposed by the National Precast Concrete Association (2010).

Credit	SS Credit 5.1	SS Credit 6.1 & 6.2	MR Credits 2.1 & 2.2	MR Credits 4.1 & 4.2	MR Credits 5.1 & 5.2
<b>Description</b>	Site Development: Protect or restore habitat	Stormwater Design: quantity and quality control	Construction Waste Management: divert from disposal (50%=1 pt.; 75%=2 pts.)	Recycled Content: post-consumer plus half pre-consumer (10%=1 pt.; 20%=2 pts.)	Regional Materials: processed and manufactured regionally (10%=1 pt.; 20%=2 pts.)
<b>Credits Available</b>	1	2	2	2	2
<b>Comments</b>	Due to precast concrete manholes being plant cast and are delivered to the site ready to set so they require very minimal site disturbance to install.	Most stormwater management plans will require manholes in the design to properly handle the stormwater runoff. Precast concrete manholes are the superior choice.	Precast concrete manholes are plant cast and delivered to the site ready to set and create minimal to zero amounts of onsite waste material.	Precast Concrete Manholes may contain supplementary cementitious materials such as fly ash and blast furnace slag which will add to the project's recycled content goals.	The vast majority of materials that go into the construction of precast concrete manholes are within a 500-mile radius of the precast plant.

studies available in the literature on altered manhole mix designs are mentioned her in.

De Belie, et. al. (2004) studied the effect of using high sulfate resistant Portland cement and slag cement concrete on the durability of sewer components due to sulfate acid attack. It was found that both cements had a favorable effect on the durability under sulfate acid attack. According to the study carried out by Parande et. al (2011) Portland Pozzolana Cement (PPC) concrete was found to perform better than Ordinary Portland cement (OPC) concrete under several sewer environmental conditions. Soroushian, et. al. (2009) proposed the use of water repelling additives together with silica fume to reduce the microbial induced corrosion in sanitary concrete sewer systems.

Lepech (2005) went to a larger extend by developing a highly ductile cement based material to produce prefabricated sustainable infrastructures named Engineered Cementations Composites (ECC). The main advantage of this material is that it has an elastic-plastic stress strain curve in tension similar to that of ductile materials, unlike concrete which has a brittle behavior. The ECC has shown to be more durable than traditional concrete due to its ductility in tension. Another advantage of this material is that it reduces the amount of CO<sub>2</sub> emission associated with the materials used to produce the structure components due to the fact that it incorporates numerous industrial wastes such as waste foundry sand, cement kiln dust and fly ash. The newly launched manhole system called the Kijlstra manhole has used an improved concrete mix design that had replacement of up to 40% of cement with slag which has low associated carbon emissions (the company keeps the actual recipe as its intellectual property). An independ-

ent study made by Carbon Clear to quantify the green house gas emissions associated with this manhole system, found that it is up to 65% more carbon efficient and up to 65% lighter in weight than traditional systems (Today's concrete technology, 2010).

### 3.2 The manhole's casting and production procedures

In the last decade precast concrete manufacturers have spend tremendous effort on increase the sustainability of their products. Apart from the efforts done on altering the mix design of manholes, altering the manufacturing processes to reduce the energy consumption and the CO<sub>2</sub> emission associated with manholes production was one of the main directions that manhole manufacturers fallowed. The production method also influenced the manhole durability through its effect on the water cement ratio and water absorption values (De Belie, et. al., 2004). There are two main casting methods for manholes: the wet casting and the dry casting. In the wet casting, conventional concrete or self consolidating concrete is usually used. This method gives space for the modified mixes mentioned in the previous heading to be utilized. The use of self compacting concrete in the wet casting method will save the energy required to agitate the concrete in the dry casting method. Also, the wet casting method saves the energy associated with the steam curing due to the overnight drying technique adopted.

The foremost advantage of the dry casting method is the fast formwork removal which accelerates the production process. This is due to the use of zero slump concrete that usually requires intensive energy to agitate and vibrate and then steam cure the produced concrete manhole. The main sustainability efforts for this casting method concentrate on develop-

ing less energy intensive equipment for agitating and vibrating the concrete. An example is the use of high-performance electro-hydraulic drive unit of the pressing tools to get maximum process capacity at minimum energy consumption (Schlosser Pfeiffer, 2010).

Other manufacturers went in the direction of trying to eliminate the onsite concrete casting during the installation process by producing prebenched manholes in the factory to reduce the onsite installation time. Some manhole manufacturers went to the extent of developing a process in which industrial robots directly produce monolithic manhole bases with any desired channel and connection layout (Prinzing GmbH, 2010).

### 3.3 The treatment of the manhole's surface

When highly corrosive environments are expected one of the ways used to help protect the precast concrete manholes and pipes from deterioration and by turn increase their sustainability is treating the surface of the manhole and pipes by coating or lining their inner surface. The coating or spraying of the concrete sewer system is mainly to deactivate or reduce the bacteria causing the generation of the concrete corroding agents. Hewayde, et. al. (2007) proposed using innovative coating to reduce biological generation of sulfide in concrete sewer systems and increase its durability. Cuprous oxide or silver oxide were used as coating materials and proven to dramatically reduce the sulfide generation by sulfate reducing bacteria. Sydney, et. al. (1996) proposed spraying a high pH mixture in the crown of the sewer system in a process called the "crown spray" to deactivate the sulfur or sulfide oxidizing bacteria that causes the corrosion of the system.

## 4 PROPOSED SUSTAINABLE MANHOLE DESIGN

During the course of this research a sustainable manhole design was proposed for circular precast concrete manholes. The proposed design involved altering the structural composition of the manhole by removing the steel reinforcement from the manhole base. The Canadian code permits altering the manhole design only if full scale testing was performed. First the feasibility of the proposed manhole was studied from the structural point by performing full scale testing, followed by an extensive numerical parametric study. Then the sustainability of the proposed manhole was evaluated.

### 4.1 Full scale testing of the proposed sustainable manhole design

The main aim of this part of the research is to evaluate the state of strains in the precast concrete manhole and state of stresses in the soil surrounding the manhole and beneath the base to verify the feasibility of the proposed non-reinforced base manhole from the structural point of view. Two full-scale proposed sustainable manholes, one 1200 mm in diameter and one 1500 mm in diameter, were tested in the large-scale geotechnical testing facility (LSGTF) at the University of Western Ontario. Twenty seven load tests were performed on the manholes, which involved loads representing the Ontario truck loads incorporated in the Canadian Highway Bridge Code. None of the manhole sections tested in the experimental program experienced any cracks under any of the loading conditions. This indicated that the altered design behavior is satisfactory under the critical Ontario truck loads, which are the design loads used in practice. The detailed description of the state of stresses and strains in the tested manholes components as well as the pressure in the soil surrounding the manholes is fully described in Sabouni and El Naggar, (2011a).

### 4.2 Numerical investigation of the proposed sustainable manhole design

A finite element numerical investigation on the proposed sustainable manhole design was carried out using Plaxis 3D. The developed model was calibrated against the experimental results presented in Sabouni and El Naggar, (2011a). The bending moment in the non-reinforced manhole base and the vertical stresses in the soil underneath the manholes were evaluated in a parametric study on a variety of manhole site conditions to identify the critical factors affecting the manhole response. The parameters that were investigated were: manhole depth, type of native soil around the manhole; trench width ( $T_w$ ); water table elevation ( $W_t$ ); effect of manhole stage installation; and effect of soil compaction. The results showed that the maximum base moment for the 1200 mm diameter manhole model from all loading cases was 65% less than the cracking moment. For the 1500 mm diameter manhole model base, the maximum moment from all loading cases was 81% less than the cracking moment (Sabouni and El Naggar, 2011b). These results indicated that the current 1200 mm and 1500 mm diameter circular precast

concrete manholes' base designs were overly conservative.

#### *4.3 Sustainability evaluation of the proposed sustainable manhole design*

In order to evaluate the sustainability of the proposed manhole design that eliminates the base reinforcement the three sustainability pillars: environment, economic and social aspects should be studied over the expected life cycle of the manhole. The environmental aspects especially the CO<sub>2</sub> emission associated with the life cycle of a structure is a main indicator of the sustainability of the structure. The proposed manhole with the heavy reinforcing steel eliminated from its base has less CO<sub>2</sub> emission associated with its life cycle than the standard precast concrete manholes. This is mainly due to the absence of the CO<sub>2</sub> emission from the steel manufacturing, transportation and placement during casting the manhole. The lighter manhole weight will reduce the amount of CO<sub>2</sub> emission associated with the transportation of the manhole to the construction site and the installation. This is beside the less natural materials consumed in the production of the proposed manhole and by turn less material to recycle or dispose at the end of life of the manhole.

From the economic point of view the elimination of the heavy steel bars in the manhole base will eliminate the cost associated with the production and transportation of the rebars first of all. Then it will reduce the labor cost and production time needed to manufacture this manhole. The resulting manhole will be lighter than the standard manhole, which may reduce the transportation and installation efforts and costs. At the end of the manhole life the cost of demolishing would be less due to the absence of the heavy amount of reinforcement that would need to be recycled in the traditional precast concrete manhole.

The proposed manhole has a positive social impact due to the absence of the steel mesh which reduces the manufacturing time and increases the factory's productivity. The main advantage of the proposed manhole is that it is more durable than the traditional manhole - where several main durability issues are strongly affected by the presence of the steel rebars in the structures- especially in a harsh environment such as that in a sewer or storm water system. The higher durability of the manhole will reduce the maintenance and replacement efforts needed during the life of the manhole, and by turn reduces the interruption time for the whole sewer or storm water system. This is also counted as a posi-

tive environmental and economical impact of the proposed manhole. Combining this proposed manhole design that eliminates the steel rebars from the base with one or more of the efforts described in the sustainability effort on manhole part of this paper will even increase the sustainability of this proposed manhole.

## 5 CONCLUSIONS

The sustainability of built structures is one of the main concerns in the last decade. In order to evaluate the sustainability of precast concrete manholes a life cycle assessment scheme for precast concrete manholes is proposed in this paper. The sustainability efforts associated with precast concrete manholes and available in the literature have also been presented. Based on the fact that the present design of precast concrete manhole bases' in Canada is over conservative, a sustainable manhole design is proposed, which eliminates the steel reinforcement from the manhole base. According to the Canadian standards altering the manhole standard design is allowed only if verified by full scale testing. In the course of verifying the proposed manhole design a full scale testing of several precast concrete manholes were performed under critical conditions of the standard Ontario truck load and were proven to be satisfactory. A numerical investigation was also carried out to confirm the validity of this design for different manhole configurations and also has proven to be satisfactory. After verifying the structural validity of the proposed manhole design the sustainability of this manhole was studied over the life cycle of the manhole according to the three sustainability pillars: environment, economic and social aspects.

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