Final Report

Demonstration of the Viability of Using Tire Derived Aggregate (TDA) to Replace Natural Material (NM) in Residential Home Basement Construction

By
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This project was a collaboration among OTR Recycling Corp, Tire Stewardship Manitoba (TSM), Manitoba Hydro (MH) and Red River College (RRC). Work conducted throughout the project was led by The Paul Charette-Manitoba Applied Research Chair in Sustainable Construction. The financial and technical contributions provided by the collaborators have been invaluable for the successful completion of the project and are greatly acknowledged.

Many others have provided supports; either financial or in-kind, throughout the design and construction of the Experimental House at the demonstration site. They are listed below and their supports are also appreciated.

Finally, the Chair expresses a huge note of gratitude on behalf of all collaborators to the many College students who participated in the project since it began. Their inputs and hard work have made us all proud to be part of RRC.
Executive Summary

This project began with queries from two main stakeholders, Manitoba Hydro and the tire recycling industry in Manitoba. While Manitoba Hydro’s interest was to find out if using TDA in home basement construction would save energy; Manitoba tire recycling industry’s interest was to explore a new value-added market for TDA. The research investigations conducted by Red River College (RRC) during the past five years have focused on addressing those primary interests, and results of the work have shown promising responses to those inquiries.

The investigations began with reviewing prior work which revealed that TDA has been successfully used in many civil engineering applications and that several standards, such as those by American Standards for Testing Materials (ASTM D 6270) have been in place to guide its use in some specific applications.

Realizing that performance may vary in different applications and locations, our research work has therefore focused on understanding, measuring and assessing the technical, environmental and economic viability of using TDA in this particular application, namely backfilling basement walls in residential home construction in Manitoba and similar jurisdictions, in-lieu of natural material (NM).

The technical assessment showed that TDA has no negative effects and may even perform better than natural material when used as backfill and underneath the slab of home basements. This assessment, which is based on both laboratory and on site measurements of the many parameters defining such performance, has revealed that:

- Heat losses through basement walls may be reduced significantly
- Moisture retention of backfill is significantly reduced and its drainage ability is significantly increased
- Lateral pressure of backfill on basement walls is significantly reduced

Aside from diverting wasted tires from landfills, the environmental assessment showed that using TDA in this application would have no effects on ground water qualities and no risk of overheating. Furthermore, it may actually improve indoor environmental qualities, even slightly. This was manifested in reducing Radon emission levels through basement floors & walls as well as decreasing moisture levels of interior drywalls’ surfaces.

As for the economic assessment, there are two components that may be considered. The first is related to the potential savings achieved from:

1) designing and building basement walls according to lesser lateral forces,
2) keeping the backfill behind the walls as dry as possible, and
3) reduced energy consumption resulting from reducing heat losses.

The second component is related to the cost of supplying and placing TDA in comparison to clean fills. A preliminary analysis of current market prices showed that while clean fills’ cost ranges from $600 to $3,600 for a typical (24’ by 36’) basement construction, TDA cost ranges from $450 to $900, depending on size gradation.

Based on these assessments as well as all the research work documented in this report, it is believed that TDA presents a value-added product not only to the tire recycling industry and the utility companies but also to the building industry and building owners & managers in Manitoba and similar jurisdiction. In fact, some in the building sector began to recognize this value; thanks
to the knowledge mobilization efforts undertaken by all the stakeholders in this project. Examples of such awareness can be seen in:

- statements by the City of Winnipeg Engineers who believe that TDA can be used in city projects, as long as geotechnical reports are accompanying the construction permits docs

- calls from owners of old homes; such as those living in River Heights, Mb to replace their basements backfill with TDA to repair walls’ damages caused by swelling of the existing NM fill over the years. (Please refer to the Appendix: Using TDA to replace existing backfill in older and historical homes to mitigate moisture leakage problems- Summary of the demonstration project at 263 Waverly Street, Winnipeg, Manitoba)

- willingness of developers to use TDA; such as those currently considering using it in their 35 unit- independent living – seniors residence in Beausejour, Mb

It is hoped that sharing the findings included in this report with more stakeholders from the engineering, architectural, home building industries as well as from municipal and provincial building authorities would help in gaining more understanding of TDA’s value and confidence in its use in the intended application.
First: Types, Standards and Applications of Recycled Tires

Scrap rubber tires have been put into other uses almost since cars first introduced into our lives. Due to the many diverse properties that it possesses; such as toughness, flexibility, longevity, light weight and consistency; scrap rubber tires were used in many applications from making shoe soles, as shock protections in harbors to beautiful landscape tiles and turfs for children play ground. Other uses included landfill covers and fuel for cement manufacturing and hydro production plants.
Recycled rubber tires have also been used in many civil engineering applications. These applications include bases and sub-bases for road construction, embankment stabilization & fill for retaining walls, as shown in the examples below:

1 CIVIL ENGINEERING APPLICATION USING TIRE DERIVED AGGREGATE (TDA) PRESENTED BY: Stacey M. Patenaude
CalRecycle, California
Due to the increased use of recycled tires in civil engineering applications, standards were developed to regulate such use, the most known of which is that by The American Society for Testing and Materials: ASTM D 6270: “Standard Practice for Use of Scrap Tires in Civil Engineering Applications”.

The Standard provides a comprehensive list of terms and definitions for scrap tires used in civil engineering applications such as:

- **Tire Chips** – pieces of scrap tires that are generally 0.05 to 2 inches in size and have most of the wire removed.
- **Tire Shreds** – pieces of scrap tires that are generally 2 to 12 inches in size.
- **Tire Derived Aggregate (TDA)** – any combination of tire chips and tire shreds used as an alternative to conventional mineral soil/aggregate in civil engineering applications.

**TDA** is an engineered product made by cutting scrap tires into small pieces using shredders with sharp knives to obtain clean cuts. Screening is sometimes necessary to remove excess dirt and undesired small rubber particles. Magnetic separation is sometime used to remove unwanted portions of metal fragments. Foreign objects, such as wood, must be removed manually.

Sources of **TDA** include: cars and small RV & light trucks, and Off-The-Road (OTR) tires collected from large agriculture and mining equipment. While properties such as: weight, density, specific gravity of **TDA** are generally common and have well established values, others such as: thermal, hydraulic conductivity, and compressibility are dependent on source of tires and size distribution as well as the application itself. For example, thermal conductivity was found to increase with size of shred. **TDA** from car and light truck may have higher compressibility than that from OTR tires. On the other hand, size distribution may be more important for road construction than for leachate applications.

In Manitoba, old tire collection and disposal is the responsibility of Tire Stewardship Manitoba (TSM). According to TSM\(^2\); all scrap tires that are available for collection and recycling in the Province are repurposed into products such as: paving, landscape and roofing tiles; fill for road construction, 2"TDA/Leachate (majority), sidewalks, crumb or blast mats.

As the markets for such products may experience changes in supply & demand from time to time, higher inventories as well as more crowded landfills may call for exploring other markets, and hence the main objective for this project. The project is focused on determining and demonstrating the technical, economic and environmental feasibility of using **TDA** in a new civil engineering application, that is backfill and underneath slabs for residential homes’ basement construction.

The following sections include background of the project and the results of the research work conducted throughout the past few years.

Second: Use of Tire Derived Aggregate (TDA) in Basement Construction

Background of the Project:
In 2013, Manitoba Hydro (MH) approached the researchers at the Red River College (RRC) with an idea for an applied research project. The idea was based on discussions with the tire recycling industry in Manitoba that was interested in exploring the feasibility of using tire derived aggregate (TDA) underneath and around (i.e. backfill) home basement floor slabs and walls. MH had an interest to support the investigation because of the potential energy saving resulting from enhancing the insulation value of the basement foundation. The Tire recycling industry, represented by OTR Recycling Corp. and Tire Stewardship Manitoba (TSM) was interested in the project as their mandate is to promote economically viable end-uses and market applications for scrap tires, thus diverting used tires from simply ending up in landfills. Red River College (RRC) became interested in the project since it aligned with the College strategic research plans and therefore offered to work on the project by providing testing and research services to help in exploring the feasibility of utilizing TDA in this application.

To explore this feasibility; it was decided that the research and testing activities should be undertaken in phases. In Phase I of the project, the focus of the work was on understanding the effects of short term loading on the compressibility related behavior of TDA material.

Based on the compressibility test results, the work progressed to Phase II where the focus was on determining other physical and mechanical properties that describe the short term behavior of TDA. All tests conducted during Phases I & II were small scale laboratory type of experiments.

Based on the test results in Phase II, the project advanced into Phase III where the focus became on determining the long term performance of TDA in this particular application through a full scale demonstration.

The following sections present summaries of the work and results of the tests in each phase:
Phase I

An introductory set of experiments were conducted in CARSI laboratory at RRC to study the compressibility behavior of TDA due to short term loadings. The compressibility was simply defined as the ratio between settlements of the material under different loads to its original thickness. A series of tests were conducted the main conclusion of which was that in a 4” to 6” thick layer of TDA, the maximum compressibility values observed were insignificant. The Figure below shows the test arrangement and results.

Other conclusions reached were as follows:

- The initial settlement under the equivalent weight of concrete slab could reach a maximum of 25% of the original thickness.
- Thickness of the rubber mat (4” or 6”) does not significantly change the compressibility of the mat under the applied loads. This might be attributed to the possibility of the diminishing effects of the applied loads in the lower levels of the mat, and as such not contributing to extra settlement.
- Additional live loads (up to 4.8 kPa) do not cause significant extra settlements (less than 10 mm).
- Removing the live loads will rebound the slab for a few millimeters.

It should be noted that compressibility values recorded by others\(^3\) have ranged between 10% to 35% depending on source and level of compaction and vertical applied stresses.

\(^3\) Publication # DRRR-2011-038, Civil Eng. Applications using TDA, Dana Humphrey
Phase II

For Phase II, the client (OTR Recycling & TSM) solicited the services of a local consulting firm, Trek Geotechnical Inc. (TG), for their expertise in soil mechanics and designing foundations in Manitoba. The firm advised and collaborated with RRC researchers on the types and methodologies of the tests needed to be conducted and also reviewed the results of the tests which included:

First: Gradation Distribution Tests

Due to the large sizes, and irregular shapes of the TDA, the test procedure followed the intent of ASTM C136 as close as possible. Sample selected using splitting was around 80 kg.

![Image of TDA Gradation Curve]

First: Gradation Distribution Tests

Sieve analysis was conducted using Gilson large screeners and the resulting gradation curve was as shown in the graph above.

Second: TDA Hydraulic Conductivity Tests:

Hydraulic conductivity is the property of the TDA that describes the ease with which water can move through its voids under specified hydraulic conditions. It mainly depends on the permeability of the material under different loadings and the degree of saturation. The figure below shows the test set up and results.

![Image of Hydraulic Conductivity Test Setup]

Second: TDA Hydraulic Conductivity Tests

The graph shows test results.

Hydraulic Conductivity of TDA Particles

<table>
<thead>
<tr>
<th>Material</th>
<th>Initial Conductivity</th>
<th>Final Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>0.6500</td>
<td>0.6100</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.6700</td>
<td>0.6400</td>
</tr>
<tr>
<td>Silt, loam</td>
<td>0.0002</td>
<td>0.0002</td>
</tr>
<tr>
<td>Till</td>
<td>0.0002</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Comparison between the OTR TDA and other materials with respect to the conductivity.
It should be noted that according to the same reference noted above\textsuperscript{3}, hydraulic conductivities of tire shreds ranging from 0.58 cm/sec to 23.5 cm/sec were reported in several investigations.

In addition to determining the hydraulic conductivity, the following parameters were also calculated:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry (Bulk) Unit Weight of Tire Shreds</td>
<td>4.891 kN/m\textsuperscript{3}</td>
</tr>
<tr>
<td>Porosity</td>
<td>5.299 x 10\textsuperscript{-1}</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>1.127</td>
</tr>
<tr>
<td>Specific Gravity of Tire Shreds</td>
<td>1.063</td>
</tr>
</tbody>
</table>

The unit weight of shredded tires recorded in the literature\textsuperscript{4} was found to range from 5 to 6 kN/m\textsuperscript{3}

**Third: TDA Lateral Pressure Test:**

A small scale test was designed at CARSI for the specific purpose of understanding & determining how much lateral pressure exerted on basement walls when TDA is used as backfill. The Figure below shows test set up and results

Values of $K_0$ recorded in the literature\textsuperscript{4} by different researchers ranged between .26 and 0.4.

It should be noted that results of the tests conducted throughout Phases I & II were published in the Annual NOCMAT 2015 Conference, in Winnipeg, Manitoba\textsuperscript{4}

\textsuperscript{4} Shokry Rashwan et al, "Investigating the Feasibility of Using Tire Derived Aggregate (TDA) for Basement Construction Applications in Manitoba," NOCMAT 2015, Winnipeg MB. 
Phase III

Based on the results from Phases I & II, the project then progressed into the demonstration stage where a full scale basement of a typical home, using TDA as backfill and underneath the slab, was built. This part of the research project, began early in 2016 and continued for two years (spring of 2018), has focused on two main tasks the outcome of which would be used to potentially introduce TDA as a green building material into the home building market. These tasks were:

First: Measuring and analyzing the properties that describe the long-term performance of TDA using a multitude of instrumentations and tools as well as developing “best practice” guidelines for TDA use in this application.

Second: Conducting economic and environmental assessments to address issues such as lifecycle & cost-benefit analysis for use of TDA in this new application.

Before presenting work done on those tasks, the following sections present summary description of developing the full scale basement used for the demonstration project.

Site selection:
After considering a number of options, the site for the building was selected at the North West corner of RRC Notre Dame Campus. The map below shows the selected site.
Design & Construction of the “Experimental House”:
The building included a typical 24 ft by 36 ft full basement with makeshift top for weather protection. The basement was divided into two identical parts, where TDA was used as backfill and underneath the slab on one side and natural material (NM) was used on the other side.

Design of the building was completed by local designers, ft3 Architecture and Lavergne Engineering, during summer of 2015 and a building permit was granted by the City of Winnipeg in September 2015. The figure below shows plan view and x-section of the building as well as a copy of the building permit.
Once permit was issued, work began on site in October 2015 and was completed in January 2016. Site related project work included:

- Installation of all sensors stations around the perimeter. The following pics show this part of the work.
It should be noted that the monitoring and measuring system developed for this project was described in a publication presented at the annual conference of Canadian Society of Civil Engineering at London, Ontario in June 20165.

- 7 days after walls were all filled with concrete, backfilling then began and was completed in early November with adding TDA in the southern half and natural material in the northern half of the basement. On the TDA side, the backfilling process was conducted by lifting one tote full of material at a time with the excavator boom and directs it on top of placement location, then the bottom of the tote was cut open letting the TDA free fall in its location. On the other side, natural material was scooped with the excavator bucket and dumped in the voids. The process continued till all voids were filled on both sides to a height of 4.5 ft (approx.) from the bottom ground level. Geotextile sheets were then used on top of TDA and in between TDA and natural materials on both sides. Clean fill layer was then added on top of the geotextile sheets on the TDA side as well as on top of the natural material to bring the height of backfill to almost 6 ft on all sides. Some compaction was applied during this process using the excavator bucket and tracks. The pictures below shows the backfilling process.

The work on the basement concrete slab was followed and completed before mid-November, 2015. Half the slab was built on top of TDA and the other half on natural material. Multi point sensors were installed in both sides to measure temperature and moisture variations. Also strain gauges were installed on the reinforcement, on both sides of the slab, to record any differences in deformations. Framing of floor joists then began and was completed by late November. The following pics show that part of the work
Following the backfilling, the main floor beam was lifted on top of the walls and the 2 telescopic posts and remaining framing work was completed by early December 2015.

During summer of 2016, some landscaping work was also done by the college’s green space students. The pic below shows the building, called the Experimental House.
Results of the Demonstration and Assessments of TDA performance over 2-years

What are performance parameters measured during the demonstration project??
1. Heat losses
2. Moisture retention & Drainage ability
3. Lateral pressure on walls
4. Differential movements of slab
5. Radon levels
6. Ground water qualities
7. Indoor air qualities
8. Flash point

The general methodology followed for measuring above performance parameters
While specific values for some of those parameters were determined for TDA during small scale tests in laboratory settings and under controlled conditions (e.g. hydraulic conductivity and lateral pressure), in this demonstration, analysis are based on comparing measured performance between both sides of the basement, the TDA and natural material (NM) sides. As shown in the sketch below, sensors stations were distributed evenly between the two sides. Each station included: temperature, moisture and lateral pressure sensors.

The following sections present summaries of the sensors data results and the comparative analysis conducted:
1. **Heat Losses**

As mentioned above, analysis of the backfill performance was based on comparing the measurements of the different parameters of **TDA** vs **NM**. Therefore, heat loss analysis were based on assessing the differences in backfill sustained temperatures for **TDA** vs that for **NM** sides. The hypothesis adopted in the analysis was: assuming that indoor temperatures and basement walls’ air tightness and thermal properties are kept the same on both sides; then higher sustained backfill temperature translates into lower heat losses through basement walls, using heat conduction principles.

To work on the heat loss analysis, let us first review those temperature differences over two years' period and try to understand the causes of such differences. The figure below shows an overview comparison between average temperatures from all **TDA** sensors vs that from all **NM** sensors.

A number of observations may be drawn from the graph including:

- **Average** temperatures for both **TDA** and **NM** follow a general pattern with time which is common for backfills; that is high and low temperatures follow warmer and colder outside weather conditions.
- While higher differences between **TDA** and **NM** average temperatures as well as higher variability in the recorded averages themselves were noted from start of the demonstration until summer of 2017; a more “tighter” differences and variability began to emerge after that.
  
  Reason for this may be explained as follows: no mechanical compaction was applied and no topsoil was added following the backfilling in January 2016. In late summer of 2016, mechanical compaction was applied to the **TDA** south & east sides prior to placing landscape paving bricks at the south side and topsoil was added all around the perimeter. In addition, natural occurring soil sustained consolidation is suspected to be another factor in producing that tighter patterns noticed from August 2017 and thereafter.

- It is also suspected that those factors, i.e. compaction of **TDA** and consolidation of **NM**, are contributing to the overall rising trend in average temperatures for both sides over 2 years period as shown in the same figure above.

It is important to note that the above time graph presents overall averages of **TDA** and **NM**, each of which is the average value calculated from measuring 18 temperature sensors placed on each side. These overall averages comparison, which is also presented in the following statistical distributions graphs (histograms and boxplots), show that there is a difference of about 1° C between the two sides, with **TDA** average 16.12° C (61° F) and **NM** average of 15.34° C (59.5° F). It should be noted that these averages are in line with what is cited in the literature. It is also
interesting to note that this difference is statistically significant as indicated by the p-value taking a less than 0.05 when the t-test (significance test) was performed, as shown in the figure below. This may mean that TDA’s sustained temperature is always higher than that for NM, even though the overall difference may appear insignificant.

Nevertheless, while the average values shown above give an overview of the differences in sustained temperatures between the two sides; a more closer and precise analysis necessitates reviewing individual sensors at different sides of the basement. The two figures below show the average temperatures at each sensor at each side of the basement over two years period.
As suspected, the above graphs show variability in the temperature measurements at the different sensors. Although factors affecting the variation in temperature measurements at the different sensors on both sides may include possible orientation/location of the individual sensors, external conditions and/or sensors’ technical glitches, the focus of this analysis has been on the effects resulting from the differences in the thermal properties of both TDA and NM. Reason for making such assertion is that due to the small size of the building, orientation or location of the sensors may not have significant effect on the temperature measurements. In addition, in analyzing the differences between the two sides, all efforts are made to consider comparable and closely located sensors on both sides. For example, the following graph shows the differences in temperature averages for sensors 3A and 5A, both located on the east side and approximately 6ft apart, where sensor 3A is on TDA side and 5A on NM side.

In focusing on the effects resulting from the differences in thermal properties of both TDA and NM, compaction on the TDA side was found to significantly affect the backfill sustained temperature. For example; sustained average temperatures on TDA side that experienced compaction and placement of paving bricks was higher than on any other locations, whether on TDA or NM sides. This is evident from studying following figure that shows the average temperature for sensor 24A which is located on TDA side before and after compaction. The differences in sustained average temperatures; 15.6° C and 21.6° C for before and after compaction, was found to be statistically significant as demonstrated by p-value of zero. It should also be noted that the variability in the average values measured after compaction was significantly lower than that measured before compaction as demonstrated in the standard deviation values of 8.4° C before compaction and 3.4° C after compaction.
In comparison, measured temperatures for the sensors facing the west side, where no compaction was applied, shows that sustained temperatures for the NM is generally higher than that for TDA, as shown in the figure below.

In order to validate such observation and further to measure the effect of compacting TDA on sustained temperature, a laboratory controlled experiment was conducted in summer of 2017 where different compaction levels were applied to TDA filled and insulated pipe, shown below. From the experiment, it was established that the optimum level of compaction necessary to
reduce the voids ratio and achieve highest possible sustained temperature should be between 15% and 20%, approximately.

It was also found that TDA from processing car and light trucks tires (PLT) requires less compaction to achieve same levels of voids ration and sustained temperatures in comparison with that processed from OTR (off-the-road) tires.

Based on the above analysis, it can be stated that it is possible to achieve significant differences between TDA and NM sustained temperatures, provided that an optimum levels of compaction and in turn voids ratio is attained for TDA.

Now to illustrate how this difference in temperatures may translate to lower heat losses, let us consider for example the differences between north and south sides of the building (graph below) right after compacting TDA on the south side. These differences, averaging between 2 °C to 8 °C during heating months (October 16 to April 17) would translate into significant thermal resistance differences and in turn significant lower heat losses from basement walls.
Notwithstanding other forms of heat losses, this significant difference may be illustrated with the following simple calculations. Assuming that the heat losses on each side are:

\[ Q_{\text{TDA}} = A \times U \times \Delta T_{\text{TDA}} \]
\[ Q_{\text{NM}} = A \times U \times \Delta T_{\text{NM}} \]

Where:

- \( Q_{\text{TDA}} \) & \( Q_{\text{NM}} \) are heat losses on both sides of the basement in kW
- \( A \) is the below grade area of the walls in m² on each side
- \( U \) is the thermal conductivity of the below grade walls (W/m².K°)
- \( \Delta T_{\text{TDA}} \) & \( \Delta T_{\text{NM}} \) are the difference between backfill and indoor temperatures in °C. Assuming that the indoor temperatures on both sides of the basement are the same. Then the difference in heat losses may be expressed as: \( A \times U \times (\Delta T_{\text{TDA}} - \Delta T_{\text{NM}}) \)

To put this into perspective, let's examine the period from December 15, 2016 to January 15, 2017.

During this period, as shown in the graph above for the north (NM) and south (TDA) sides, if the below grade wall area for this whole basement is 55.74 m², then the difference in heat losses in Watt is:

\[ 55.74 \times (U) \times (3930) = (219060 \times U) \text{ Watt} \]

& considering the temperatures are measured hourly, then the difference in energy consumption in kWh would be:

\[ (219060 \times U) \times 1/1000 = (219 \times U) \text{ kWh} \]

Using a range of \( U \) values for basement walls, the following graph shows the range of potential consumption and cost savings during the same period if TDA replaces NM in backfilling basement walls in a typical 24’ X 36’ home.
It should be mentioned that the earlier noted reference\(^9\) included results of determining the thermal conductivity of tire shreds and comparing it with soil average thermal conductivity. The average TDA thermal conductivity was determined as 0.12 Btu/hr-ft.\(^{°}\)F while soil average thermal conductivity about 1 Btu/hr-ft.\(^{°}\)F, i.e. about 8 times, approximately.

### 2. Moisture retention & Drainage ability

Two approaches were used to measure these properties and in comparing between TDA and NM sides. The first; using multipoint sensors that measure levels of moisture in the backfill matrix and the second, using frequency (run time) of emptying the sump pits on both sides of the basement.

First, the figure below shows an overview comparison between average backfill moisture levels from all TDA sensors vs that from all NM sensors. The graph shows results of these measurements from July 2016 to February of 2018. Due to sensors calibration glitches, measurements from January to June 2016 were eliminated from analysis.

The figure shows a clear and rather significant difference in moisture levels between TDA and NM. This is also shown in the following graphs where t-test results indicate the significant difference between the two levels of moisture, with p-value is zero.
Unlike the variability observed for the temperature measurements before at the different sides, the moisture measurements in all sides of the basement walls show that clear and significant difference exist in all sides, as shown in the figure below.
In addition to using the multipoint sensors for measuring the moisture levels, frequencies of operations for the sump pumps at both sides of the basement were also measured during the spring and rain season of 2016. The following graph shows that the sump pump on the TDA side has higher frequency of operation compared with that on the NM side.

Generally, the measurements shown in the above graphs confirm results of the hydraulic conductivity test conducted at the laboratory during Phase II. Specifically, the measurements show that moisture levels in the natural material backfill is almost twice of that at the TDA backfill. They also show that the difference in moisture levels is higher during the summer time and decreases in the cold weather. This may be validated by considering the results of the sump pump run times where rates of emptying the pits are much higher during the warmer months. The sump pump measurements also show that drainage ability of TDA is more than double that for natural materials.

Of course this particular property of TDA has a significant effect on reducing moisture leakage through basement walls, a common problem in many Manitoba homes, particularly older ones.

3. **Lateral pressure on basement walls**

The importance of measuring this property is that it gives us an idea about the levels of lateral forces applied to the basement walls from TDA as compared with those from NM. These lateral forces are used to design basement walls, i.e. to determine their thickness and levels of reinforcement. These forces are also used in estimating the serviceability characteristics of walls over time; e.g. cracking development and propagation and the subsequent impacts.

It should be noted that this property was evaluated through a controlled laboratory experiment during Phase II, where commercial earth pressure cells were used to determine the coefficient of lateral pressure at rest \(K_o\) for TDA which was found to be less than 50% of that known for NM.
However, for this demonstration and for the purpose of comparing the lateral pressures of TDA vs NM, a special device was developed and used on site in lieu of the costly earth pressure cells. The device includes simple strain gauges connected to a cantilever that bends with the lateral pressure induced by the backfill, as shown in the figure below.
Using this simple device, we were able to get a general view of the comparison between lateral pressures of TDA vs NM, as shown in the figure below.

The above figure shows that strains resulting from the lateral pressure of natural material is higher than that for TDA. Since strains are directly proportional to stresses, it can be stated that lateral pressure induced by natural material (NM) is definitely higher than that by TDA. Statistical tests further show that the differences between the two sets of measurements are significant, as shown in the figure below and indicated in the value of probability parameter $P = 0$. This is significant since it confirms that TDA would always produce lesser pressure on basement walls which would validate the results of the small scale test shown earlier for $K_0 = 0.19$. 

**Two-sample T for TDA vs NM**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDA</td>
<td>9935</td>
<td>5944</td>
<td>2869</td>
</tr>
<tr>
<td>NM</td>
<td>9935</td>
<td>6876</td>
<td>2794</td>
</tr>
</tbody>
</table>

T-Test of difference = 0 (vs not =): P-Value = 0.000 < 0.05
It should be noted that the same pattern of strain distribution difference between TDA and NM was also observed at all sides of basement walls, as shown in the figures below.

In addition to the strain differences between TDA and NM, this pattern also shows that the stains and in turn the lateral forces follow temperature changes i.e. increase and decrease during wormer and colder periods. Using this observation, which has been cited in prior work\(^3\), it was possible to develop a prediction relationship/model that correlates TDA temperature and moisture to lateral pressure. The following graph shows the developed prediction model in comparison with the actual measurements.

The importance of developing such a model is that it can be used in future design work without the need to replicate site measurements.
Monitoring the strains at different locations has also shown that upper strains are generally lower than bottom strains, as shown in the figure below which is consistent with normal distributions of backfill materials against basement or retaining walls.

Using the above information along with the $k_o$ (at rest horizontal to vertical load ratio), the value established during the small scale test, the following simple example demonstrates the difference in lateral pressure between TDA and natural material.

The example above shows that the value of the horizontal force $H$ resulting from natural fill material is 8 to 9 times as much as that resulting from TDA. This significant difference would potentially translate into structurally thinner and less reinforced wall sections and in turn lower cost for basement walls backfilled with TDA compared with those backfilled with natural fill material.
4. **Differential movements of the basement concrete floor**
The concrete floor slab was supported by the concrete piles. However, 4 to 6 inches of TDA and natural soil were packed underneath the slab at both sides. The purpose of measuring the differential movements on both sides was to determine the effects of "swelling" of each type of subbase material on the slab above it. This is to address one of the common issues for concrete basement slabs that occurs when soil underneath swells due to changes in moisture conditions and may cause the concrete floor to crack.

In order to perform these measurements, the floor was divided into stations & grids as shown in the figure below. Three level circuits were conducted to measure the elevation of the basement floor over a course of 18 months. The elevations were measured with respect to the pile supporting the tele post in the natural backfill section of the basement, with the assumption that this pile did not move vertically during this time. The level circuits were conducted using a Leica NA2 automatic optical level and a levelling rod.

The figures below show the floor profiles at those grids listed in the figure above. Generally, floor levels on both sides have shown very little and insignificant movements, all within 4 mm. However, an interesting observations may be noted from reviewing the profiles shown in the figures below. While the floor levels on the TDA side indicate settlement or sagging, the levels on the natural material side indicate rising or heaving. Even though the values are insignificant, but this
observation may refer to the expected soil swelling that normally occur and causes the concrete basement slab to crack over time.
5. **Radon Emissions Levels**
Radon levels were also measured at both sides of the basement with different conditions of ventilation. The objectives of measuring Radon levels were:

- Generally, to determine the difference between different kinds of ventilations such active, passive and no ventilation
- Specifically, to determine the difference between the radon levels (bq/m\(^3\)) at both the **TDA** and Natural Material (NM) sides of the basement

Two measuring devices were used, the first is a handheld that does not automatically store measured data and the second was provided by Health Canada that has data storage capabilities.
Although statistically insignificant, but results show slightly lower Radon emission average values appeared on the TDA side in comparison to those on NM side, as shown in the figure below.

These differences were noticed during all of the three types of ventilation. It is suspected that these differences may be caused by:

a) The pressure differences between outdoors and indoors, which drives the Radon gas from outside to inside, are higher on the NM side than on the TDA side.

b) The higher moisture content on the NM side compared with that on TDA side may also contribute to such higher Radon emission levels.

On the other hand, significant difference (probability value P-value is 0) was determined between the three different types of ventilations, when considering the basement as one room, as shown below.

It should be noted that factors such as precipitations and temperatures were also found to affect emission values, on both sides, in similar ways.
6. **Ground water qualities**

Series of tests were conducted from January to September 2016 to determine levels of ground water qualities following the construction of the Experimental House and use of TDA in backfilling the basement walls. The groundwater sampling and tests were conducted by independent certified laboratory; ASL Global, while limits used for comparisons were based on Health Canada guidelines for chemicals in drinking water. Except for Benzene test, results, as shown in the graphs below, indicate no “out of the norm” effects due to use of TDA as compared with the results from samples collected from the natural material side.

A number of efforts were further made to understand the reason and implications of the higher levels of Benzene shown in the first test result. Benzene, being one of the chemicals used in manufacturing tires, is expected to be released if TDA is submersed in water. As will be discussed later in the “Best Practices”, higher levels of moisture noticed at TDA side during the spring of 2016 were suspected to be caused by blocking the drainage paths and subsequent rise of surface water in the backfill. The first ground water samples were collected and tested during that time. Of course this condition was remedied during the summer and fall of 2016, and drainage of the water from the sump pits was improved and as a result TDA moisture levels dropped significantly. Having the TDA in dryer conditions has resulted in no more releasing of Benzene into ground water and therefore, the two repeated tests following the first one, within 6 months period, have shown no traces of Benzene in the water samples. In addition, and according to experts’ opinions, it appears that amounts of Benzene is limited and it disappears with time. This analysis was confirmed by Richela Kimie Maeda⁶, who conducted extensive study on effects of TDA on ground water quality. The following are excerpts from his thesis:

“The laboratory experiment suggests that, of the 83 tested constituents, benzene, methyl isobutyl ketone (MIBK), cadmium, zinc, iron, manganese, total phosphate, and total suspended solids (TSS) are leached from TDA and dissolved oxygen (DO) is altered by TDA. For the eight constituents suspected to leach from TDA, a decrease in release over time was observed, with release rates for the majority of these constituents reaching values below their respective detection limits by the end of the experiment….The rate at which metals leach from TDA is the highest when continuously submerged....”

The thesis ends with the following conclusion:

“The results of this study have demonstrated that the use of TDA as a fill material in civil engineering applications is a responsible method of recycling automotive scrap tires. TDA fills that are seasonally or always saturated are very unlikely to compromise the quality of the receiving water. The number of potentially harmful compounds leaching from the TDA is limited, and the rate of leaching is sufficiently low that the concentrations of these compounds in the surrounding waters do not pose any environmental degradation. In addition, sufficient dilution and soil adsorption effects further reduce impacts compounds might have on receiving waters. Sufficient dilution and soil adsorption processes further reduce the potential impacts that these compounds might have on any receiving water”.

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7. **Indoor Environmental Qualities**

In addition to Radon measurements shown earlier, indoor air/environmental qualities included measuring a number of other parameters such as: levels of CO, CO₂, relative humidity, air contaminants such as dust particles and volatile organic compounds (VOC). Two different commercial devices were used and preliminary results show no significant differences between the two sides of the basement. While no traces for CO or CO₂ detected, particle counts were between 100 and 1000 while relative humidity ranged from 35% to 45%. These ranges describe good to normal indoor conditions. It should be noted that the Experimental House was classified as “low occupancy” facility.

However, measurements for the moisture contents of the indoor drywalls showed that average drywall moisture content on the natural material side of the basement is higher than that for the drywall on the TDA side, as shown in the figure below. Although measurements slightly vary according to time of the year and indoor humidity, the overall averages determined were 10% on the natural material side and 7% on the TDA side.

![Indoor Drywalls Average Moisture for TDA vs Nat Mat](image)

The importance of measuring the moisture content of the indoor drywalls is that it gives us a means of estimating moisture migration through the walls, if any, as well as it indicates the potential for mold growth. Mold requires moisture to survive, so protecting lumber and wood structures from moisture would help prevent mold growth. Normally, a drywall moisture content above 10% may signal a problem. From the figure above, we can see that the moisture content on the natural material side has exceeded 10% at many times particularly in the early spring of 2017.

8. **Flash point**

In addition to the comparative analysis presented above which is based on measuring the relative different performance characteristics on both sides of the basement, flash point test was conducted on TDA to determine at what level of temperature TDA my ignite on its own. The test was conducted at ALS laboratory (independent Laboratory) and results were that the flash point is above 75 C°

It should be noted that ASTM D 6270 [ASTM, 2008] provides guidelines to minimize the internal heating potential of a TDA layer. These guidelines recommend that TDA fill thickness must be limited to 10 ft to prevent heating problems. Considering this new application, i.e. backfilling basement walls, the fill thickness may never exceed 5 to 6 ft and with an average width of 2 ft, there are no potential for reaching that limit for internal heating.
**Third: Recommended Guidelines for “Best Practice”**

The research investigations conducted during the past five years have combined many different elements that are essential to fully address the questions and issues brought forward by the stakeholders. The scope of work included reviewing and assessing prior research, conducting controlled laboratory experiments to measure specific and short-term properties of TDA as well as undertaking a full scale demonstration to understand and determine the long-term behavior of TDA in comparison with NM. The analysis and assessments of measured properties and performance were conducted using a combination of advanced computational tools and where possible, experts’ opinions.

The overall conclusion of the investigations may be summed up as follows: **Tire Derived Aggregate (TDA) may replace natural fill material (NM) in backfilling walls and underneath the slab of home basements. As a matter of fact, TDA can be more effective in this application than NM. HOWEVER, in order to reap the maximum benefits for using TDA, few guidelines should be followed during the preparation and placement of the material. These guidelines are recommended based on the work conducted throughout this project.**

The following summarizes the recommended best practice guidelines as they relate to the corresponding performance parameters, which were presented and analyzed in details in the previous sections:

**Heat Losses:**

The thermal resistance performance of TDA can be greatly compromised if large pockets of voids exist in the backfill, particularly during cold months. Increasing the volumes of these pockets may actually reduce TDA’s ability to retain heat and as a result; heat losses through basement walls may increase. In order to optimize (maximize) the thermal resistance of TDA, the following guidelines are recommended:

- **Size and gradation distribution:** the smaller the maximum size of TDA the lesser the resulting voids. Although material used in this project was considered 4” minus, larger material was common. Large pieces particularly with irregular shapes contribute to formation of bridging and in turn large voids. 2” minus material would be ideal for use in this application. Gradation, on the other hand, should follow similar distribution pattern shown early in the report.

- **Compaction:** due to the natural composition and shape of TDA particles, all efforts should be made to optimize its voids ratio to be within these limits identified earlier. This may be achieved through working on eliminating bridging and distributing the material so that to fill those large pockets. TDA may be placed in lifts (6” to 8” thick) and applying compaction to each lift. Hand held vibrating equipment or small rollers may be more effective in this application.

- **Sealing:** depending on the depth of the dugout, it is recommended that a layer of top soil, representing 15% to 20% of the total depth, to be added and compacted on top of the TDA backfill. This will prevent retained heat from being lost, particularly during cold windy days.

These general guidelines are depicted in the following photos.
Moisture Retention & Drainage Ability:
The pump rate for draining water from the sump pits is almost the same on TDA and NM sides. However, because the hydraulic conductivity on TDA side is much higher than on NM side, it is expected that frequency of emptying the pits on the TDA side would be higher than that on the NM side which leaves the TDA moisture content at lower levels than NM. However, it was observed that during the first spring of the demonstration (2016), elevated moisture contents, even at alarming levels were recorded on TDA side. That was caused due to blocking of the drainage passes (e.g. weep tiles) by fine materials that were mixed with the surface water as it was rapidly seeping through the backfill and lack of proper sealing of the TDA. This situation was rectified in the summer of 2016 by wrapping the top of the TDA with geotextile after compacting the TDA layer. It is therefore recommended that in addition to use properly graded TDA material, proper compaction and sealing, the TDA must be wrapped with geotextile material, as depicted in the side sketch, that will act as filter preventing fine materials from seeping into and plugging drainage passes.

Lateral Pressure:
Lack of proper gradation and compaction may result in distorting the profile commonly familiar for backfill material pressure on the basement walls. Although this will not change the fact that TDA exerts less pressure than NM, but calculating such pressure may become a cumbersome task for designers.
**Fourth: Where to Go From Here?**

The economic assessment conducted in this project was rudimentary and focused on costs of producing and delivering TDA to a small site similar to that used for the Experimental House. The assessment, as summarized in the following figure, indicates that cost of using TDA can be less than that for NM in some cases. However, in-depth economic analysis is recommended to be conducted to address other potential benefits such as design and construction of thinner basement walls and lower operation & maintenance costs of buildings over their lifecycles.

![Graph: Approximate total costs for walls backfill and underneath slab 4" base in a typical home basement]

In addition to the above recommendations; the tire recycling industry is also encouraged to continue improving the process of preparing and placing TDA. Examples of these improvements may include prefabricating packages of TDA material in such a way that would facilitate its delivery and placement on site. This would provide for a good quality control and maintain consistency for backfill required properties such as uniform gradation and optimum voids ratio.

These continuous improvements coupled with concerted efforts to market TDA as “green and sustainable” building material will definitely add more value to this product and further promote more uses in the targeted building sector. It is recommended that the industry should continue perusing the Environmental Product Declaration (EPD) registration offered by the Canadian Standards Association (CSA). The value of having EPD is that it would encourage developers to use TDA in green buildings and in particular in LEED certified buildings.

Part of this project entailed introducing the stakeholders to the EPD application process. The following figure summarizes such task.
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>who</th>
<th>Estimated $$$</th>
<th>Estimated time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PCR- Product Category Rule: A document that establishes the requirements for performing a LCA and developing an EPD for a defined category of products</td>
<td>CSA group</td>
<td>$15K to $25K</td>
<td>4 to 6 months</td>
</tr>
<tr>
<td>2</td>
<td>LCA- Life Cycle Analysis: Study determining the environmental impacts of a product at specified stages of its lifecycle, from raw material acquisition through production, use and end-of-life.</td>
<td>Independent consultant (1)</td>
<td>$9K to $12K</td>
<td>1 to 3 months</td>
</tr>
<tr>
<td>3</td>
<td>EPD- Environment Product Declaration: Third party verified public statement, based on a LCA, that summarizes a product’s environmental impact – enabling comparisons between similar products.</td>
<td>Independent consultant (2)</td>
<td>$4K to $5K</td>
<td>1 to 2 months</td>
</tr>
<tr>
<td>4</td>
<td>Verifying LCA and EPD:</td>
<td>CSA group</td>
<td>$3K and $1K annual fees</td>
<td>Within 1 month</td>
</tr>
<tr>
<td>5</td>
<td>Registration with CSA and ISO</td>
<td>CSA group</td>
<td>$3K and $1K annual fees</td>
<td>Within 1 month</td>
</tr>
</tbody>
</table>
Executive Summary

Living in an old home has its perks! Spacious rooms, high ceilings, craftsmanship of old wood & marble that all give charming character and speak to the home’s history. On the flip side, basements of such homes, especially those located in areas like Winnipeg, are often plagued with water leakage and moisture related problems. The primary culprit is the seasonal changes in the soil surrounding the basement foundations due to wetting and drying. The soil in Winnipeg area, as shown in the map below, has characteristics of an “expansive clay” type. These kind of soils expand when wet and shrink when it is dry.

The more water this soil absorbs the more its volume increases. It is estimated that expansions of ten percent or more are not uncommon. This change in volume can exert significant force on the basement walls and floor to cause serious damage such as cracking and subsequent moisture infiltration and water leakage. Although other reasons exacerbating the problem may include lack of proper drainage and adequate moisture control in old homes’ basements; soil volume changes remains the significant cause of the problem. As homes get older and number of repeated cycles
of wetting and drying increases, so does the extent of damages in the foundations and subsequent moisture problems.

Traditionally, foundation consultants and contractors have used a systemic approach that focus on providing “water proofing” solutions and may include one or more of the following:

- Re-grading the ground around the house to provide better slope and flow of surface/rain water
- Installing waterproofing lining in basement walls and crawl spaces
- Sealing cracks and windows cells
- Installing sump pumps
- Snaking (clearing) the original drainage paths

Some may even replace parts of the existing backfill material with rocks or gravel to improve drainage and keep moisture conditions behind the basement walls as dry as possible.

All those solutions may provide an immediate but short term relief to the leakage problems. However, none of these solutions addresses the primary culprit, the returning of repeated cycles of expansion and shrinking of soil and subsequent damaging effects on basement walls. Even though cracks may have been sealed, this repeated actions of pressure and release would eventually lead again to opening of the cracks. Even with adding rocks or gravel to partly replace existing backfill, the surrounding soil would still exert its pressure, when wet, on the heavy rocks which in turn transfer that pressure to the basement walls.

So is it all “doom and gloom” situation when you are faced with these problems in your old home?? Well, there is a solution that provides a glimmer of hope to this rather desperate situation. A solution that would guarantee two main conditions: first: a continually dry state behind the walls and second: minimum pressure, directly or indirectly, exerted on the basement walls. This solution is the use of Tire Derived Aggregate (TDA) to replace the existing natural backfill in these old homes. TDA has three significant properties that guarantee these two main conditions. TDA has a very high hydraulic conductivity (permeability), higher compressibility and much lower weight compared with soil and rocks.

As determined in our project conducted at Red River College over the past few years and documented in the final report, TDA has twice the permeability as rocks and over ten times as much as soil. It also has one third of the weight of the soil and exerts about one eighth of the force that rocks or soil may exert on basement walls.
The knowledge of these properties have encouraged one owner of an old home in Winnipeg to try TDA in an effort to mitigate the moisture related problems that have been getting worse in their home basement over the years. The idea to try using TDA to replace existing soil backfill was welcomed by a large foundation contractor in Manitoba (Saber Industries) and of course the tire recycling industry represented by OTR and TSM. As a result of this interest, the Red River College has decided to support this endeavor as another demonstration for the use of TDA.

The home is located at 263 Waverly Street in Winnipeg, Manitoba. The area, known as River Heights, is an old neighborhood full of older homes. This particular home is over 90 years old. The current owner has lived there for almost 25 years. Immediately after moving in, the owners noticed the basement moisture leaking problem and tried over the years to mitigate it using some of the solutions mentioned above. These solutions have lessened the problems but have not addressed the causes entirely. However, as the need for turning the basement into living space has been increasing, the owners needed to properly solve the problem and eliminate any returning side effects (e.g. smells, molds, etc.).

It was therefore decided to try the use of TDA to replace existing backfill in an attempt to permanently solve the problem. However, as a demonstration project, it was decided to select the one side of the basement to be the subject of the demonstration.

Furthermore, it was decided to divide that wall into two side-by-side areas, one backfilled with TDA and the other with rocks, as illustrated in the sketch below, just to determine if any comparison between the two solutions may be visualized.
The following pics are describing the sequence of work conducted last May, 2018.

1- existing soil was first removed exposing basement foundation walls

2- water proofing & cracks sealing coat was then applied to the concrete
It should be noted that future monitoring of the moisture conditions on the interior side of the wall will be done by the owner and other interested stakeholders using a combination of visual observation and infra-red cameras or other sensing devices.

3- using supplied TDA, lifts of approximately 4" each were placed in the dug-out. Labour walked on each lift to ensure proper compaction and to eliminate any bridging caused by any large TDA pieces.

4- rigid insulation sheets were placed simultaneously.

steps 3&4 repeated till height reached edge of red bricks (approx 4 ft deep)

5- top of TDA was covered by geotextile and a 1' of sod was added on top.