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Concrete Design for Traffic Application

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CONCRETE DESIGN FOR TRAFFIC APPLICATION

by

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Abstract

Inductive charging of electronic devices is a newer technology that is capable of transferring electrical power without physical contact through wiring. Research is currently being done to find and improve ways to implement this technology on electric cars. If this type of technology pas implemented on a large scale throughout much of the country, electrical or hybrid cars could travel across counties and states without depleting their batteries.

The current problem with electric cars is that they have a limited range of travel. Even with larger batteries with much more capacitance, the range of pure electric cars usually does not exceed 100 miles (Gigaom, 2012). This is acceptable for a daily commute, but it does not hold up for cross country travel. It would be completely infeasible to travel long distances while having to stop to let your car charge for several hours. A charging system in the road way is likely the only way to rid electric cars of this impending limitation.

The main goal of this research was to design and build a suitable concrete box that can contain the necessary charging equipment, be placed underneath the road surface and maintain its structural integrity to protect the electronic equipment from crushing and moisture. Being placed a few inches below the road surface, the concrete box would need to be able to support the same loading that the roadway was designed for. The concrete box would need to uphold large compressive load while remaining durable. It should also be sturdy enough to avoid tensile cracks that could arise from handling during installation. Overall, the concrete box's design must be easily fabricated on a mass scale, light enough for ease of installation, and tough enough to maintain structural integrity over years of cyclic loading.

History of Inductive Charging

Inductive charging which is sometimes called wireless energy transfer. This newer technology has current applications in everyday devices like toothbrushes and implanted medical devices. More recently designed charging pads are used in conjunction with cell phones, I-pods, gaming controllers and just about any handheld device (Wikipedia, 2012a). Electric cars have already used this technology by using charging pads instead of a charging cable. Figure 1 shows such a pad in use by Nissan motors. More development needs to be done for this technology to meet its full potential.

Inductive charging works by having an inductive coil or ring of wiring that creates an electromagnetic field from an alternating current (i.e. power from an outlet or anything on a power grid.) The object being charged has a similar inductive coil that gets placed inside the

Figure 1: Electric car charging pad
(What's On Xiamen, 2012)

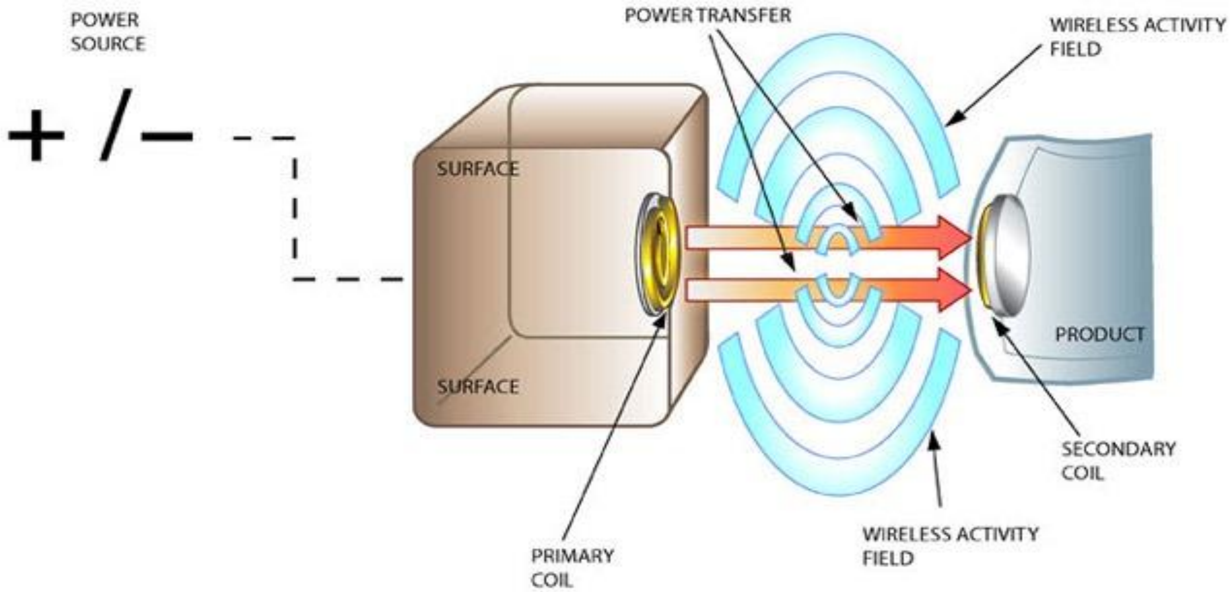

Figure 2: Inductive charging system
(Mechanical Engineering, 2012)

electromagnetic field of the charger. This secondary coil works in reverse making an electric current from the field and uses that current to charge a battery or power a device (Wikipedia, 2012a). Figure 2 gives a simplistic demonstration of how the magnetic field (called a wireless activity field in the figure) charges a device within range.

There are limitations on the efficiency of inductive charging. A direct wire transfer of energy is always more efficient but an efficiency of greater than 80% is possible (Wikipedia, 2012a.) The distance at which a device can be charged is a concern as well. Mobile devices are placed on charging pads mere centimeters away. This is not feasible for vehicles. Research has been done to widen the range of electromagnetic fields to meet compliancy with cars. An effective charging coil can be placed on the bottom of vehicles close enough to a charging plate to receive power without affecting the driving performance. But of course this is for charging a parked car.

To be able to charge or supply power to a vehicle while in transit a large infrastructure is necessary. For this reason some oppose the idea of inductive charging technology in vehicles because the cost to get a system in place would be very extensive. However systems do already exist that have similar benefits. Metro Transit of King County, Washington has a fleet of hybrid diesel-electric busses. These busses have poles above them that make contact with overhead wiring to get electrical power. (For a more visual example, this system works much like bumper cars at an amusement park.) The overhead wiring is installed in tunnels and some surface streets. The use of electricity lowers pollution output, especially in the tunnels on the busses' routs. When the infrastructure ends the bus goes to diesel power.

This bussing system is not very different from that of an inductive charging system. A charging network would be placed underneath a roadway (especially highways) so vehicles could travel long distances. An advantage to inductive charging is that it is not a mechanical system so repair costs to individual vehicles and the network would be much lower as there is no physical contact between the two. Also there is no risk of electric shock from an inductive charging system as everything in the infrastructure is underground.

It has been proposed that the charging system would consist of a charging pad placed every few feet beneath the roadway in order to make a continuous electromagnetic field for charging. The charging pads would need to be protected from compressive forces on the roadway and from water; hence some type of container needs to be designed to hold the electrical equipment. It is also worth noting that similar research is currently being done by the Korean Advance Institute of Science and Technology to provide electric charging of cars (Gizmag, 2012). Their solution is to use a conduit of cables rather that periotic charging pads.

Literature Review of Concrete Design

Concrete Composition

Concrete is a mixture of sometimes dozens of various materials to make one strong composite material. The main ingredients are cement, aggregates and water. In fine simplicity, aggregates provide strength while the cement holds the aggregates together. Water reacts with the cement to achieve this. Concrete is used as a structural material in many different applications like buildings, bridges, dams, foundations, walls, roadways and walkways.

Portland Cement

Cement is regularly called Portland cement because of its patent name. Cement is made by heating limestone which gets rid of the carbon dioxide inside. This leaves calcium oxide which is the main component of cement (Wikipedia, 2012b.) Cement works with water through a chemical process called hydration. The added water hydrates the cement making it form into a crystal like structure. Microscopically the cement crystals look very rough as seen in Figure 3. The crystals chemically bond to each other and the aggregates, partly due to the interlocking of the jagged particles, thus holding the concrete mixture together.

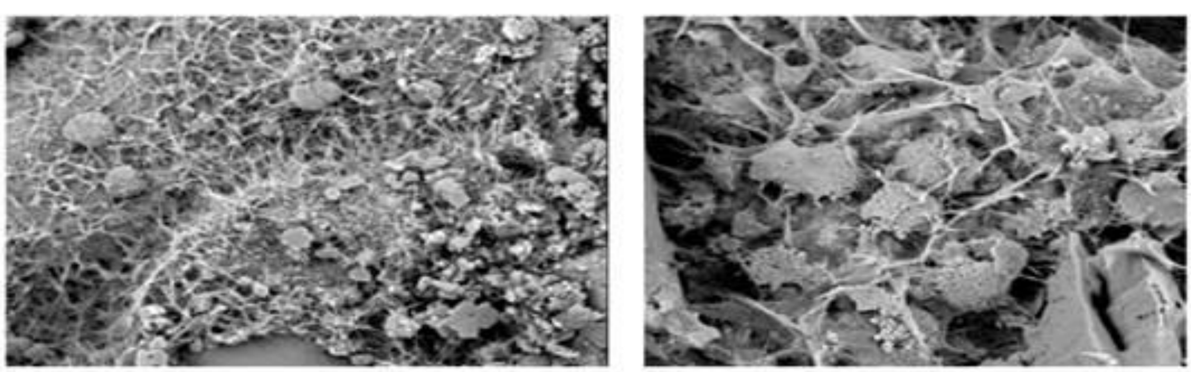

Figure 3: Microscopic view of cement
(Creative Touches, 2012)

Portland cement comes in many grades which refer to the strength. Grades like 33, 43 and 53 refer to the expected attainable 28-day compressive strength in the imperial system. So, 43 grade cement should reach 43 MPa (Ordinary Portland Cement, 2012.) In U.S. units, 4000 psi and 5000 psi are the most common types of cement although lower and higher strengths are available. In this case, the number indicates the desired ultimate bearing capacity in pounds per square inch. Cement can also come with various additives for specific design purposes like reducing frost damage. Colored cement is available for aesthetic purposes and changing the amount of ground gypsum can lengthen or reduce the curing time.

Fly ash, collected from coal burning power plants, is another common additive for cement that is commonly used in concrete mixes. Fly ash does have similar properties to cement but does have the same hydration reaction. This means that concrete with fly ash doesn't need as much water which results in less slump which can be advantageous for some situations. Furthermore, adding fly ash to a mixture allows you to lower the amount of cement needed in a mix, thus making it cheaper (Wikipedia, 2012b.)

Aggregates

Aggregates in concrete are meant to provide structural strength to the composite. Crushed stone or gravel is a common course aggregate used in most concrete mixes for structures. Rock has a very high compressive strength, and is readily available in most all parts of the world making it an ideal and cheap construction material (Wikipedia, 2012b.) Special lightweight aggregates exist to allow making lighter weight concrete. Brightly colored concrete is also available for more aesthetically sensitive applications. Three quarter in gravel is a very common size used in many construction applications. Concrete made with only coarse aggregates has an unusual property of being drainable. This is sometimes used on walkways and parking surfaces.

Fine aggregates are needed to fill space that gravel does not for most concrete structures. Sand is regularly used as a fine aggregate. While sand can be as strong as gravel, it has a much higher surface area to volume ratio as compared to gravel. This means the cement has much more surface area to bind to with sand. Excessive amounts of sand in a mix can weaken it. Figure 4 shows varying aggregate sizes including, coarse gravel, pea gravel, and sand.

Sometimes recycled materials can be used as aggregates a common one being recycled concrete. This is sometimes advantageous but recycled materials are not always available as you cannot easily increase the production of them. Crushed glass is can be used in concrete in places where glass cannot be easily smelted into new glass. Polymers like foam or shredded plastic are sometimes used in concrete mixes as well. These materials are not great structurally but they do fill up a lot of volume with little weight.

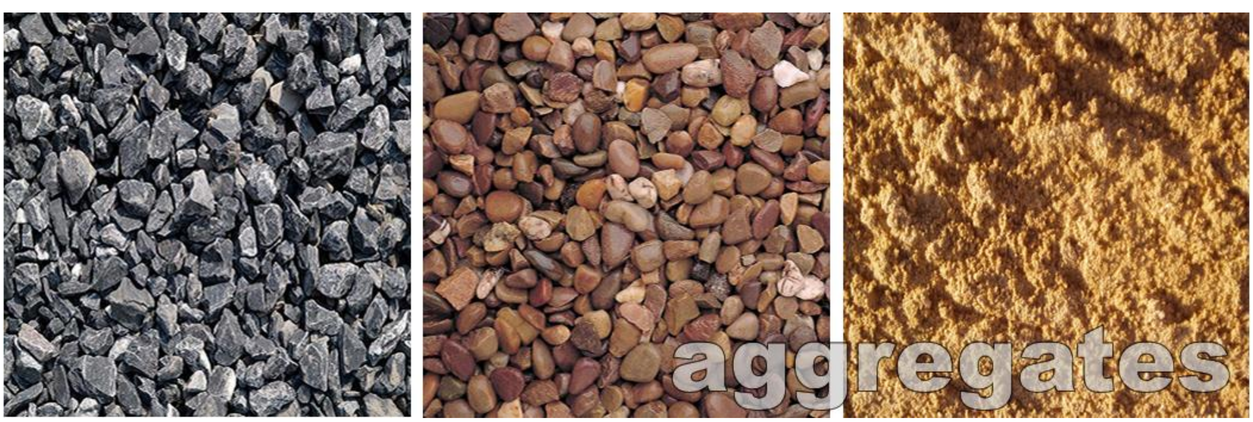

Figure 4: Differing aggregate types
(Sequatchie Concrete Service, Inc., 2012)

Fibers

Sometimes even more materials are added to a concrete mix to get desired properties. Metal, plastic and fabric fibers are added to increase the concrete strength. These fibers arrange themselves in a random pattern during mixing giving the concrete and added mesh-like reinforcement. Figure 5 shows an example of fibers that can be used in concrete. As concrete crushes tensile forces are taken up in the fibers which gives concrete both increased compression and tensile strength. Research has also shown that metal strands oriented in one direction can produce concrete with tensile capacities nearing the compressive ones on one axis.

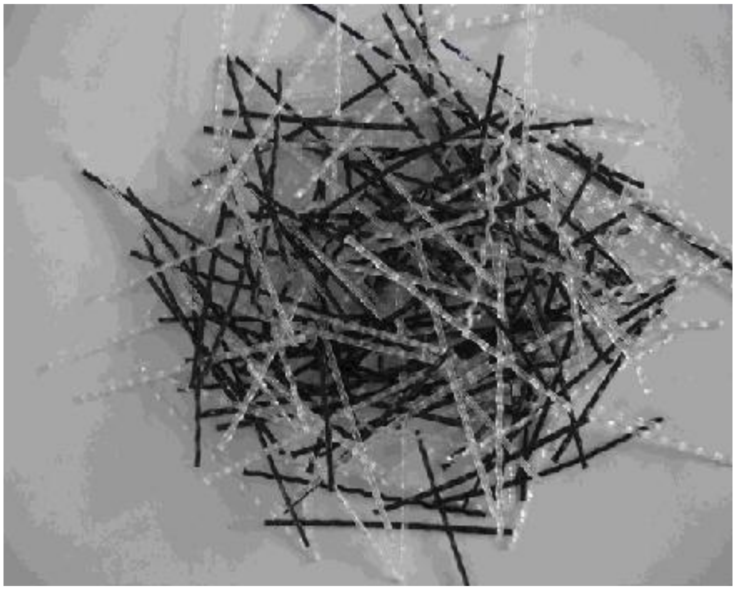

Figure 5: Polypropylene synthetic fibers (Qrbiz, 2012)

Mix Design

Designing concrete mixes is not always a simple matter. The science involved in the material properties is not so precise as to always get accurate results from predicted values. This is due to how the different materials react and work together, which is very complex. Usually when designing a concrete mix, one must make trial batches and test them to see if they meet the required specifications. Strength and durability are the most important properties of a concrete mix. However, workability or the ability to pour the concrete into the desired mold is often a determining factor. Workability can be referred to loosely as the slump of a mix which is found by filling a standard sized metal cone with concrete and measuring the loss in height when the cone is removed.

To design for strength the logical approach is to have the strongest material dominate the concrete mix. Coarse aggregates or gravels are the strongest component by their compressional force capacities but the proportion of aggregates does not correlate to the strength of concrete. The governing factor is actually the water to cement ratio (w/c.) Cement actually needs very little water to completely react and harden. Usually more water is added than necessary in order to make a workable mix. So, even though a specified strength is the first design objective, desired slump is the starting point of design.

When choosing a slump the type of project is considered like whether the concrete is for footings, walls, beams or columns. Higher slumps are usually needed when placing the concrete will be more difficult; for example when there is highly congested reinforcing steel. Early on the maximum size aggregate is considered as well. Aggregates must be smaller than the thickness of slabs, spacing of rebar and the distance between sides of forms to varying factors of safety. The amount of water needed in a mix can be determined by the size of aggregates and the desired slump. These values are actually found in tables, but they are average approximations. These values must be further adjusted after knowing the water content of the aggregates used. If wet aggregates are used at the time of mixing, the amount of water will be lowered but if the aggregate is dry, additional water to be absorbed must be added.

Now the water to cement ratio will be selected. The w/c ratio, as it relates to strength, is less empirical than the rest of the design process. The following graph in Figure 6 shows the relation of w/c and final concrete strength. Note that this is a typical relationship which is based on standard grade concrete.

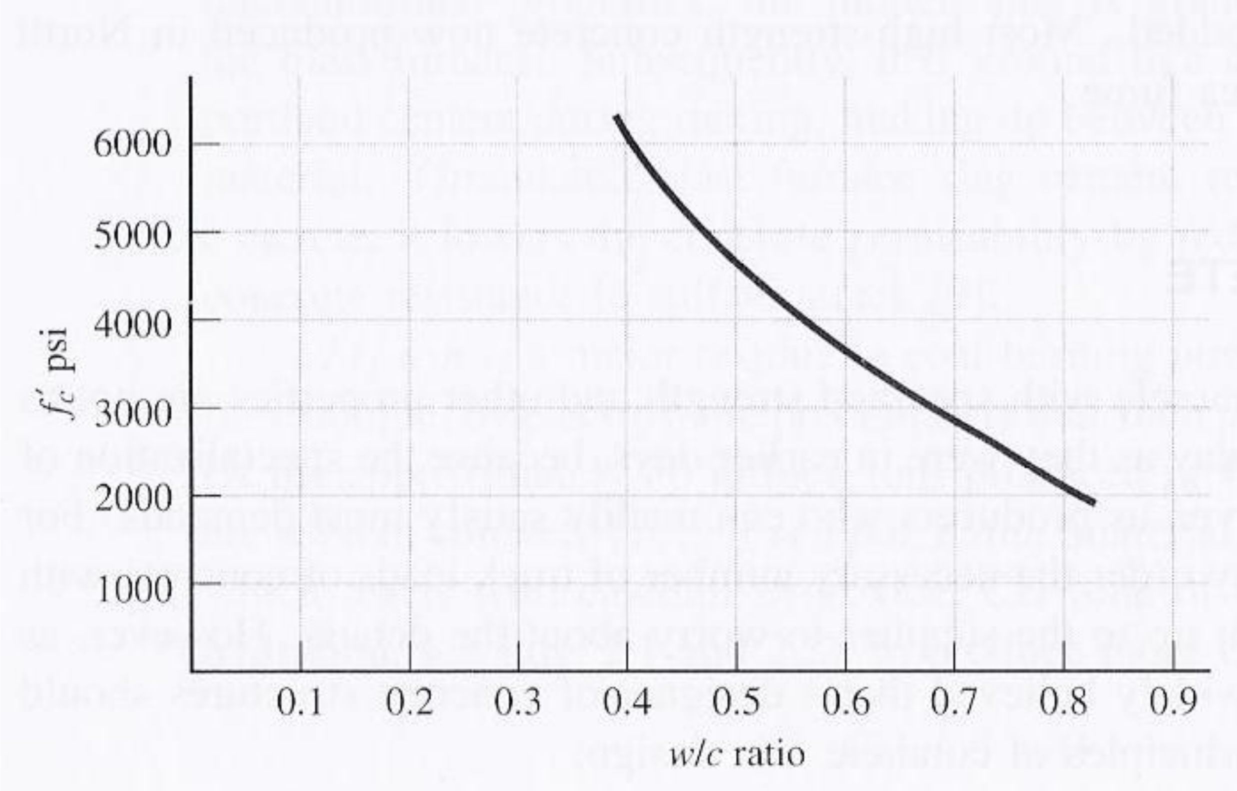

Figure 6: Typical relationship between concrete strength and water-cement ratio (Meyer, 1996)

As seen, an equal weight of water and cement will yield roughly 5000 psi concrete. The water content and w/c are used to find the cement content in a mix.

The next step in concrete mix design is to select the coarse and fine aggregate totals. In general the smaller the coarse aggregate size less volume of it should be included in the mix. This selection is based on the fineness moduli of the aggregate which is the cumulative sum of the % retained on a series of sieves. Smaller sized aggregates have lower fineness moduli like 2 to 4. The amount of sand or fine aggregate added to the mix can simply be found by subtracting the weights of all other materials from the batch size to get its desired density.

The following tables are used for the design process described in the previous paragraphs. Table 1a shows the relation of aggregate size, desired slump and initial water content. This is the first step in the design process.

APPROXIMATE MIXING WATER AND AIR CONTENT
REQUIREMENTS FOR DIFFERENT SLUMPS AND AGGREGATE SIZES

Water, lb/yd^3 of concrete for indicated nominal maximum sizes of aggregates								
Slump (in)	3/8	1/2	3/4	1	1 1/2	2	3	6
Non-air-entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	-
More than 7	-	-	-	-	-	-	-	-
Approx. amount of entrapped air in concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2

Table 1a: Design table (Meyer, 1996)

RELATIONSHIP BETWEEN w-c
RATIO AND COMPRESSIVE STRENGTH

	Water-cement ratio (by weight)	
Compressive strength at 28 days (psi)	Non- air-entrained concrete	Air-entrained concrete
6000	0.41	-
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Table 1b: Design table (Meyer, 1996)

Table 1b shows the relation between the water-cement ratio and compressive concrete strength. This is basically a tabulated form of Figure 6 and should be used to get the desired final concrete strength.

Table 1c is used to choose coarse aggregate ratio with comparisons to aggregate size and fineness moduli. As seen, when using a larger size of aggregate a greater fraction of coarse aggregate should be present in the final mix.

Table 1d gives an estimate of achieved concrete density. Once again this is based on aggregate size.

VOLUME OF COARSE AGGREGATE PER UNIT VOLUME OF CONCRETE				
Nominal maximum size of aggregate (in)	Volume of oven-dry-rodded coarse aggregate (per unit volume of concrete for different fineness moduli of fine aggregate)			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

Table 1c: Design table (Meyer, 1996)

ESTIMATE OF WEIGHT OF FRESH CONCRETE		
Nominal maximum size of aggregate (in)	First estimate of concrete weight (lb/yd^3)	
	Non- air-entrained concrete	Air-entrained concrete
3/8	3840	3710
1/2	3890	3760
3/4	3960	3840
1	4010	3850
1 1/2	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

Table 1d: Design table (Meyer, 1996)

As seen the process is not very exact. Trials should be done with tests to ensure correct slump, density, and final strength of the concrete. Subtle changes can be made for the concrete to meet chosen specifications.

Curing Processes

Curing of concrete refers to the drying or hardening of concrete. Drying is actually a misleading word as concrete does not really dry. The cement absorbs the water through hydration and turns the calcium oxide into calcium hydroxide which has the seen crystalline structure of Figure 3. This chemical process actually produces heat so concrete will continue to cure even if the concrete is moist. In fact when the surface of curing concrete is wet it will become stronger in the end.

Concrete reaches its designed strength at 28 days after being made. So for the case of 5000 grade concrete, it should reach at least 5000 psi after 28 days of curing. During any type of construction, various samples of the concrete are taken for quality control. The samples are placed in cylinders (typically 4 inch diameter and 8 inches tall) and tests are done at 28 days. If time is a concern, tests can be done at 7 days or 14 days and the corresponding 28 day strength can be correlated.

Policies on Traffic Engineering

The design of a roadway is controlled by various loads and forces. The materials the roadway is made from can alter the maximum allowable forces on the road surface. Generally when more rigid materials are used, like concrete for example, higher forces are tolerated when the same thickness of material is used. However, cracking can become a concern with rigid materials.

The design of a box to enclose electrical equipment needs to be functional in all conditions. Therefore, before starting research, a concrete box was chosen as it can function as part of the roadway and perform the necessary tasks of keeping out moisture and holding up the roadway surface.

Bearing Capacity of Roadway Surface

To analyze a roadway you must know what types of forces will be placed on it. Concrete slabs in the roadway surface are analyzed similarly to beams and girders in a building with dead and live loads. The dead loads are sometimes wearing surfaces of asphalt on the top and the live loads come in the forms of standardized lane loads and truck loads. Lane loads are distributed loads that come from a projected amount of traffic on the roadway. Truck loads represent point loads where the wheels contact the surface because they are the heaviest vehicles on the road. These wheel loads are analyzed at the extreme location conditions for concrete slabs which are the center, edges and corners (Garber & Hoel, 2009.)

In the analysis of just the designed concrete box, the governing load is a point load or truck wheel load of 27 kips. This is because the box is small enough that one wheel is all that can fit on a single box at a time. If the box can withstand a wheel load of 27 kips than it should be satisfactory for everything else.

Overall Design Process

As stated previously, the design of the container to hold electrical equipment for inductive charging has to do three main things: Support the loads of the roadway surface and keep out moisture. Installation of the container was also kept in mind so that it could be installed into the roadway without damage. Lastly the container needed to be easily constructed so that multiple units could be manufactured for large scale installation.

The main parts of design are first the concrete design which is just making concrete with enough strength to withstand the roadway forces. A wood frame to make the concrete box also needed to be designed along with a lid for the box itself.

Design of Concrete

The first part of concrete mix design is having a base point from where to start from. The concrete used in this project uses only Portland Cement, coarse and fine aggregate (gravel and sand), plastic fibers, and of course water. My first mix was pretty standard and I used some assumed values like fineness moduli to get my end calculations. The cement used for this project was readily available and rated to reach 4000 psi strength. Pea gravel, with an average particle diameter of a quarter inch was purchased and used especially for this project. Because the minimum thickness was anticipated to be one inch, the aggregates had to be small to easily fit in the wood frame. Regular three-quarter inch gravel would get caught up in corners and would not allow proper bonding of the cement.

This first design was really a base line to compare all other tests to, as well as see if the designed slump would be adequate for use in the narrow wood frame. For this reason the small wood frame that is shown in Figure 7 was made, with the anticipated 1 inch thickness. This was intended to ensure the pea gravel was small enough and to see if the concrete would easily settle into the frame without creating excessive voids.

Figure 7: Proportional practice formwork

To start the design a batch size to be 1 cubic yard was initially assumed, then by increasing or decreasing the batch components the correct proportions could be obtained. The initial slump was designed to be 6 to 7 inches. This is high but it ensures proper settling into the forms. Table 1a does not have a direct correlation so 500 lbs/yd^3 was chosen. A w/c ratio of 0.57 was chosen first as it directly correlates to 4000 psi compressive strength as seen on Table 1b. Next an aggregate ratio of 0.5 was picked. Values for a quarter inch aggregate (pea gravel) are not available but Table 1c does have a trend of smaller values with smaller sized aggregates. The weight of concrete was also interpolated from Table 1d to a value of 3800 lbs/yd^3 which seemed to work well. Lastly plastic fibers were added. The manufacturer states one bag is to be used per cubic yard of concrete so a proportional weight was taken to match the batch size.

The first design worked well as far as slump goes. The concrete poured easily into the small practice wood frame. The batch size unfortunately was underestimated as there was not enough concrete to fill both test cylinders. For future batches, a 25% increase in batch size was prepared just to be safe. It also became pertinent to make some better initial calculations. The density of gravel was assumed by looking at common weights, so this was then measured accurately and a smaller value was obtained. The plastic fibers were also re-weighed with a more accurate scale. The second designed batch (Batch B) took these corrected values into account and allowed the making of two full cylinders for testing. These changes from Batch A to Batch B can be seen in Appendix A.

The next three design batches were just subtle variations of the second. The adjustments were intended to make easily compared data while changing quantities of different parts of the mix. The amount of plastic fibers placed in the last three mixes was doubled. This was done in order to make concrete crushing tests that could clearly show the effect of plastic fibers in the mix design. It also seemed that the initial amount was not sufficient as the fibers were not very distinguishable while mixing the concrete.

Batch C was made with extra gravel to see how it would affect the bonding of the cement. This corresponded with an aggregate ratio of 0.65 instead of 0.5. Batch D was designed to have greater slump. For this mixing water was increased from 500 lbs to 600 lbs for one cubic yard. Finally, batch E was made with an improved w/c ratio to see how much strength could be gained. The water-cement ratio was lowered to 0.45 which means less water for the cement to react with. Complete design tables for all five batches and the box mixes can be found in Appendix A.

Wood Frame Design and Construction

A number of different designs were made before a suitable one was completed. A worthy design needed to be very sturdy and preferably reusable. Since plywood was going to be used in the construction of the frames I found a weather treated plywood that would hold up even after getting wet. Three quarter inch plywood was used to construct the boxes. This plywood turned out to be very strong and reliable.

Reusability was the problem with the first design of a concrete box. The joints on the first frame had built in groves on the sides and indentations on the bottom board. This made the frame extremely rigid which in turn made it difficult to remove once the concrete was cured. The frame plans are shown in the following cad drawing. Figure 8a shows the sides and walls used in the initial design. The side vies show the groves and indentations mentioned. Figure 8b is the base plate or bottom piece designs. Within the pink lines of this figure, concrete would be placed after form construction.

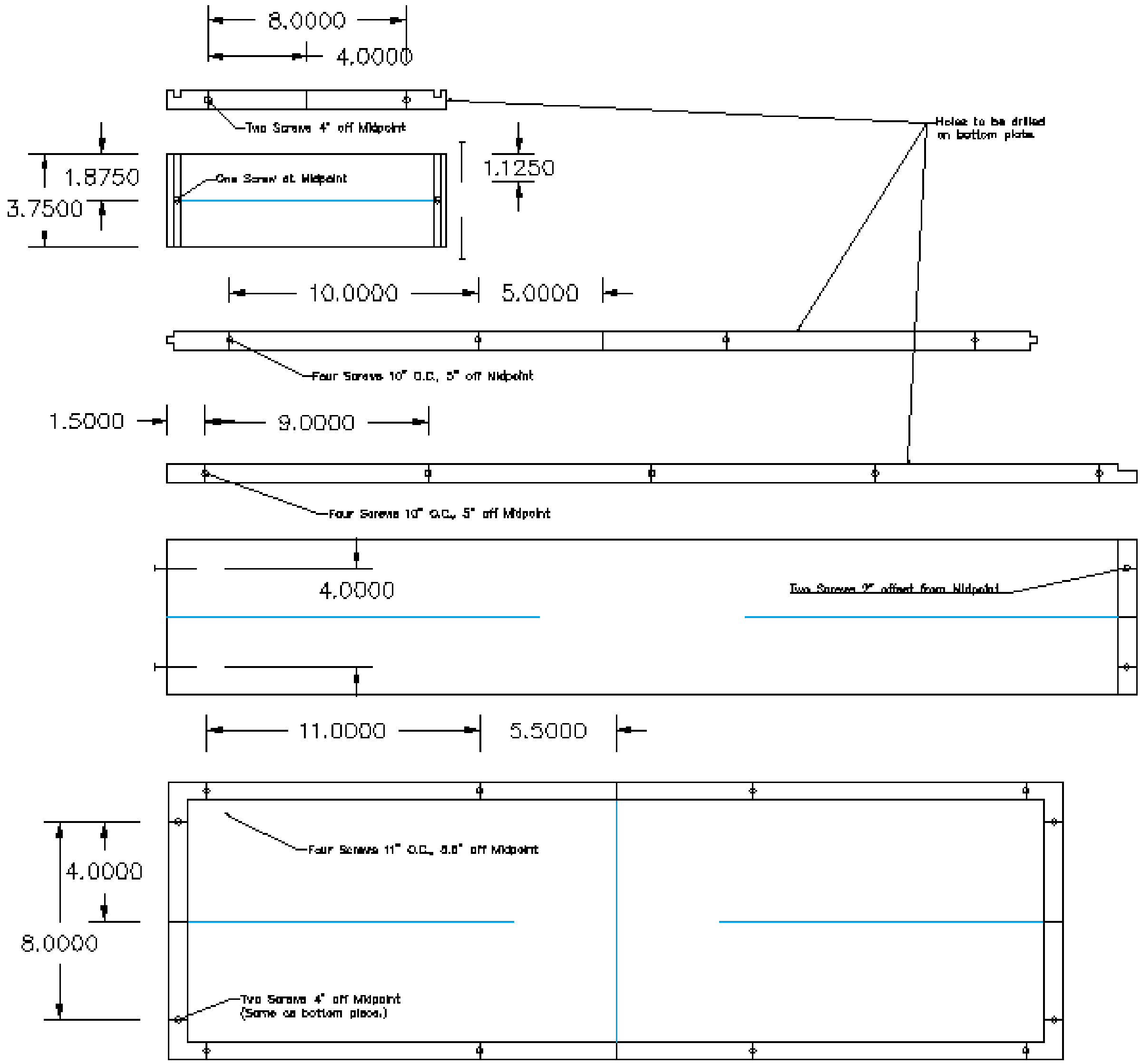

Figure 8a: AutoCAD design drawing: Sides and walls

The box has one inch walls. Two smaller walls are placed in the middle of the box to help support the fiberglass lid. The bottom thickness was also made to be one inch. The bottom of the frame is one solid piece that is 41 inches square. Although it is the bottom of the frame it becomes the top of the box and is the first piece removed when taking the frame apart.

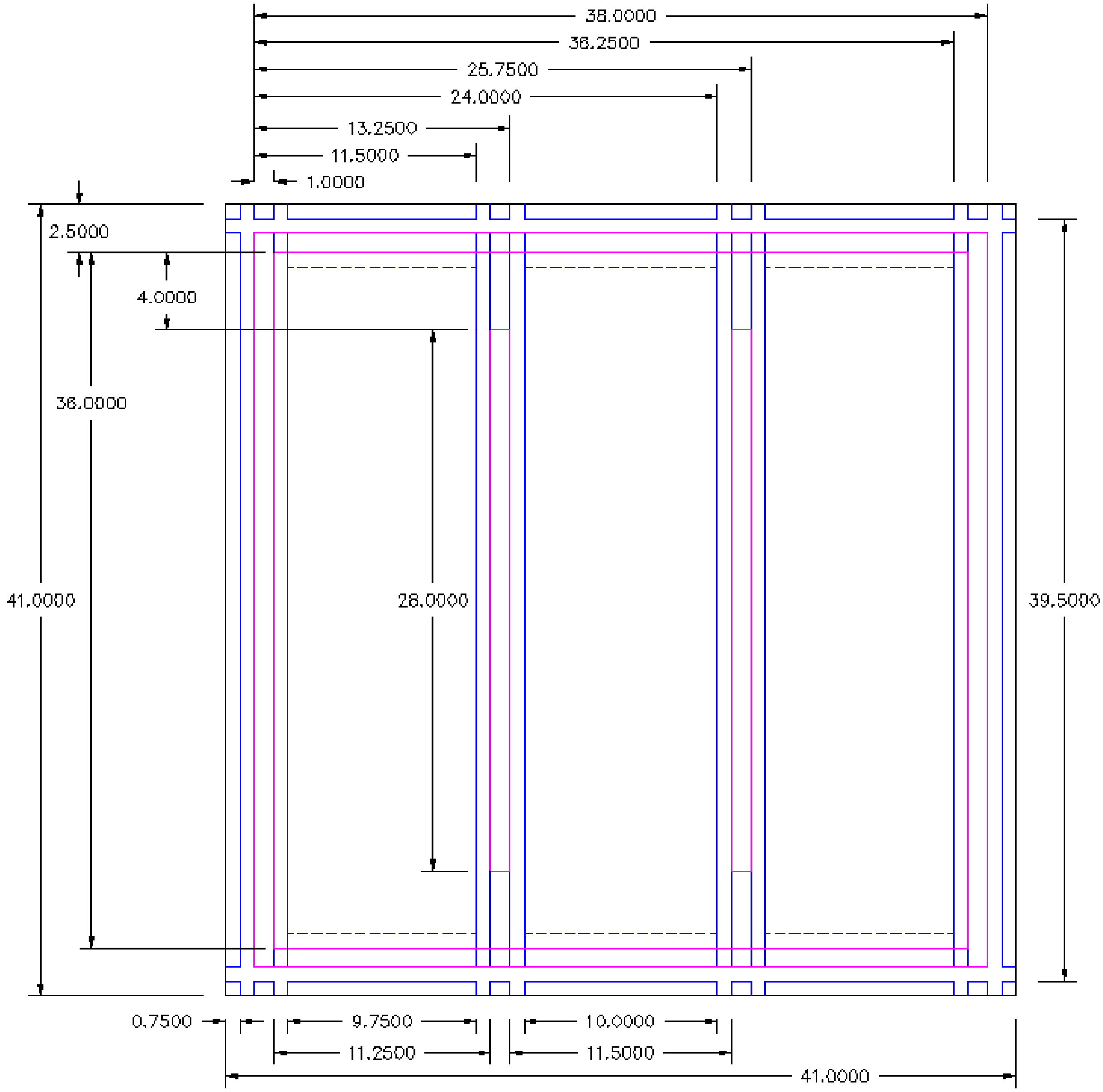

Figure 8b: AutoCAD design drawing: Bottom (Initial)

After the first concrete box was done curing it was very difficult to remove the wood from the inside of the box. The first box actually broke as I tried to pull out a piece of the framing. The main problem was that a solid piece of plywood covered the entire bottom of the three compartments of the inside of the box. This created too much frictional force on the walls

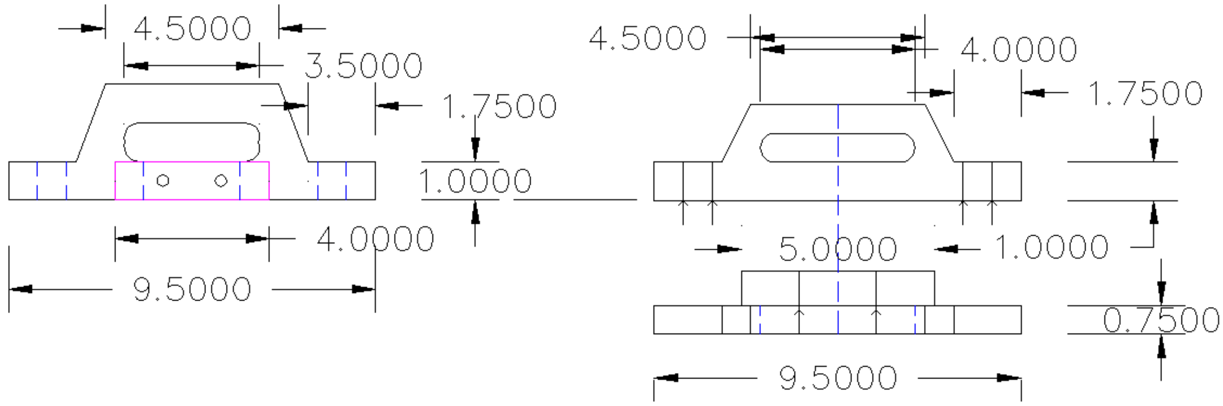

Figure 8c: AutoCAD design drawing: Handles

of the box. There initially was some anticipation of these problems so a few holes were drilled in the three bottom pieces to prevent a vacuum from forming. Small wooden handles were also designed (displayed in Figure 8c) and crafted to help pull the wood framing from the box. These modifications did not help much in the end.

In order to solve this initial problem the way the whole frame would be built was changed, mainly by altering the sizes of the side and top pieces so that there were no longer complex joints holding them together. The wall pieces extended to the bottom of the box so they would be the first to be removed. This second design was much more effective. It is shown in Figure 8d. The walls and sides are not shown again as they are all just rectangular pieces. An additional hole was placed in the outer sides of the forms and interior walls to accommodate the wiring that would need to enter into the concrete bow to power the charging equipment. These holes were only made on two opposite sides perpendicular to the interior slit walls for the box.

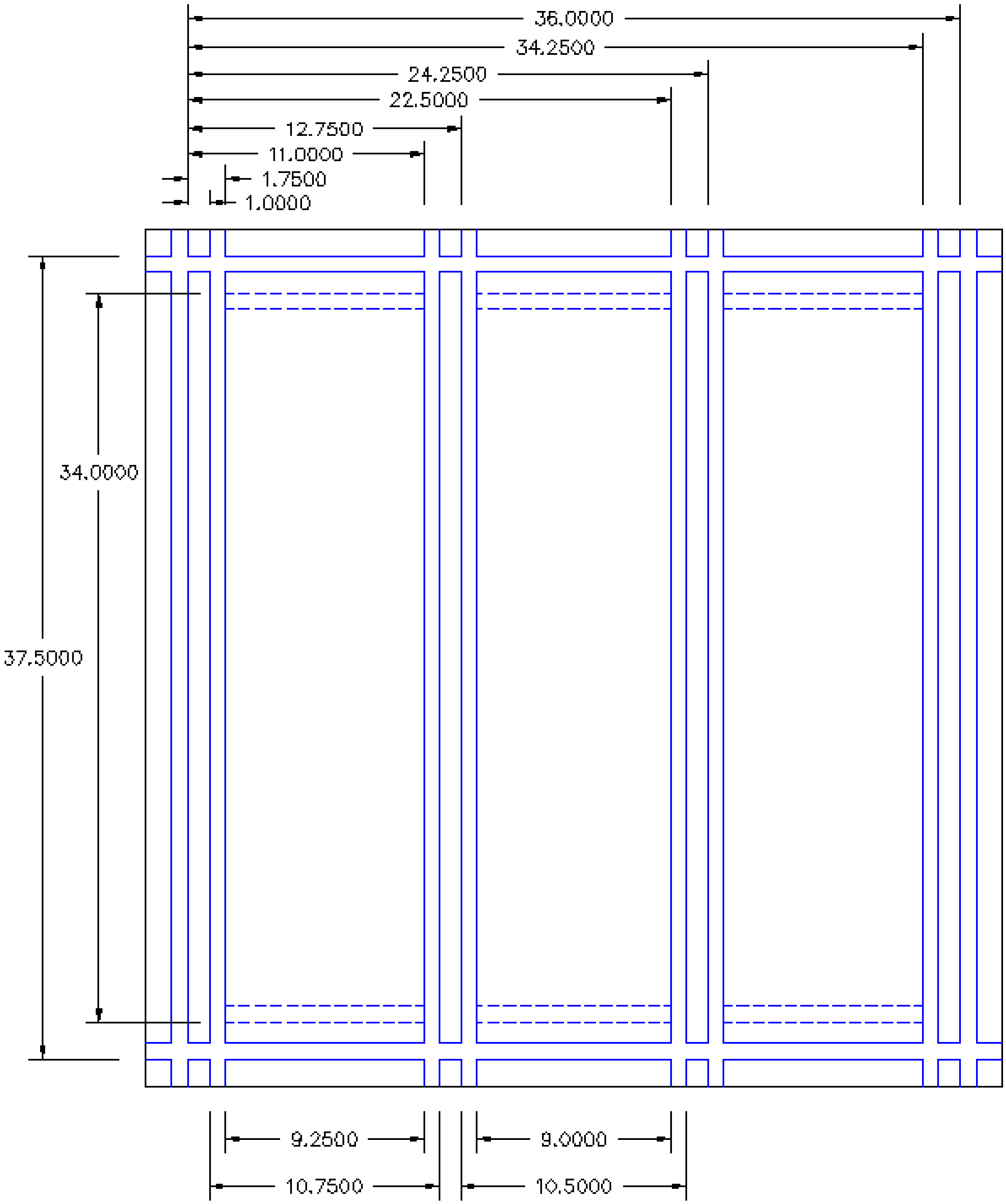

Figure 8d: AutoCAD design drawing: Bottom (Final)

All the wood frames were made of three-quarter inch weather treated plywood. The weather treatment involved coating the surface of the plywood with some type of oil that made it water resistant. This was ideal to allow the forms to be re-used as well as help the forms separate from the concrete surface.

Figure 9: Base plywood frame piece

The frames were made with only a few tools. A table saw was obviously most used to make strait and accurate cuts for most parts. A dado set (and some use of a router for harder cuts) was used to make the groves in in the large 41 inch square base piece which all the side and wall frame pieces set into. This base piece is shown in Figure 9. The indentations shown in this piece of plywood are just wide enough (3/4 inch) to allow the wall an side pieces to settle in. An entire frame unfortunately cannot be made from a single piece of 8x4 foot plywood. (I did try though and even made drawings to make sure.) A single frame can be made in less than three days which is advantageous for mass production.

Fiberglass Lid

The fiberglass lid was the expected easiest design of the project. The lid needed to be waterproof so that water wouldn't get into the box. It needed to be strong enough to resist a moment from a wheel load on an 11 inch span. A metal lid would do the trick but that is not feasible as far as expenses go. My advisor and I chose and ordered a fiberglass plate with the right specifications.

Experimental Procedure

In order to do any testing or experimentation for this project it was necessary to first create things to test. This section describes the process of making and testing concrete cylinders as well as how the actual concrete boxes were made.

Cylinder Casting

There are two standard sizes of cylinders commonly used in the United States. The larger is 12 inches tall with a 6 inch diameter base. The smaller is 8 inches tall with a 4 inch diameter base. Both cylinders can usually be used but the larger is necessary when large aggregates are in the mix. For this project the smaller 4x8 cylinders were used as they are more readily available and convenient as only small batches of concrete were to be made for testing.

The correct procedure for casting concrete cylinders to be used for testing is as follows:

1. Label the mold as to be able to identify it later. This prevents excessive disturbance of the cylinder after casting.
2. Place cylinder molds on a flat surface and have all tools close by. (Tools include mallet, 3/8" rod and flat metal strip.)
3. Place a layer of concrete in the cylinder. Usually use three equal layers are done but two layers are specified for some conditions.
4. Rod the layer (inserting rod to bottom of layer plus one inch) 25 times throughout the entire cross-section. This is to help consolidate the concrete.
5. Lightly hit the sides of the cylinder 10 to 15 times with the mallet. This closes insertion holes from the rod and alleviates some air bubbles. Hit at the level of the concrete just placed.

6. Repeat steps of filling cylinder with concrete, rodding and tapping with mallet for all three layers. Last layer should overflow slightly above the cylinder rim.
7. Strike off the top of the cylinder with the flat strip of metal to make a smooth surface.
8. Put on the cylinder lid, move cylinder to a secure place (preferably not far away) and do not disturb or move the cylinders for 48 hours.

When the outlined procedure for cylinder casting is not followed it can created bad results for the cylinder testing (NRMCA, 2012). For example if there are many voids on the surface of the cylinder it could be due to improper rodding of tapping. With excessive voids in the concrete the predicted strength will be lower than the actual value.

Construction of Concrete Boxes

The concrete boxes required 2260 cubic inches for the design on 1 inch thickness on all sides. This amount was increased to about 2500 cubic inches for the first boxes which accounts for a percentage increase and allows an additional cylinder to be made. This is about 1.45 cubic feet of concrete which actually wouldn't fit into the concrete mixer available. In order to make the boxes with what would seem like one mix it was necessary to mix the entire volume in two half mixes due to the small concrete mixer. Figure 10 shows the concrete mixer and the working area used to make the mixes. Initially all of the components (water, cement, pea gravel, sand and plastic fibers) were weighed out

Figure 10: Electric concrete mixer

and placed in plastic buckets close to the mixer. Diesel fuel was coated on the entire interior of the wood frame with a paintbrush. This was again to help the formwork separate from the concrete after curing. The procedure then was to mix half the batch, place it in the forms and rod it and immediately mixing the second half and placing it. This was pretty effective as the first half only had about 15 minutes of setting up before the second half was placed.

The second forms required a slightly larger batch size of concrete of 1.85 cubic feet. This was done to make a slightly thicker base of about 1.25 inches. This decision is explained in the results section of the report, but it seemed to be a more feasible design for practical purposes to have a stronger base to help the box settle and not crack while in the roadway. Figure 11 shows three views of the concrete box post curing.

Figure 11: Concrete box

Testing of Concrete

Testing the concrete cylinders was done on Forney Fx 600 machine. Only compressive tests were done on the cylinders. The machine uses hydraulic pumps to apply a compressive force to the concrete from the bottom up. Figure 12 is a picture of this machine. It has plastic doors on each side that allows viewing of the concrete as it is being tested. The hydraulic pump is in the base of the machine which pushes against the stationary top.

Figure 12: Cylinder testing machine

To perform the compressive concrete test you first must remove the concrete from the cylinder by cutting the mold. A utility knife works fine for this but there is a special tool designed for it. Place a metal sleeve on the top and bottom of the concrete. This sleeve has a cushion inside to help distribute an even force over possible uneven surfaces on the concrete. You must then seat the concrete inside the testing machine so the sleeves are in contact with the top and bottom load points. You can then proceed to apply a compressive load using the lower lever until failure of the concrete cylinder. It is important to not load the cylinder too fast as this may cause the concrete to fail prematurely. Adding a load of 400 psi per second or less is an acceptable rate for loading.

With 4x8 inch cylinders there is a surface area on the cylinder ends of 12.57 square inches. That means the concrete cylinders must withstand a load of about 62.8 kips to reach the wanted 5000 psi. (This change from 4000 psi was another redundancy, like a factor of safety to ensure the box would be strong enough.) The digital display screen can show the peak load that was placed on the concrete cylinder and is saved after unloading.

Fracture Types

A fracture type in a concrete cylinder basically describes the shape of the cylinder after it is broken. There are three basic shapes the concrete will break along with combinations of the shapes. One common shape of breaking is the shear shape which looks like the concrete broke through the entire cylinder at an angle. Another commonality is the cone shape where the concrete breaks in both directions making what looks like an 'x' from a side view. Both these fracture types are due to a shearing failure that should occur at an angle close to 45 degrees (American Concrete Institute,2012).

The other main shade is a columnar fracture which is when the concrete splits in a straight line down the length of the cylinder. This can occur in combination with some angled shearing surface. When this happens it sometimes means that the concrete was expanding a lot laterally. When the concrete is stronger it will limit this lateral expansion more and produce the cone or shear type fracture. Lastly sometimes the cylinder just crushes completely which represents no shape. If this crushing failure only occurs at the top it may mean that the specimen has not yet reached full strength (American Concrete Institute, 2012).

Testing of Box

As discussed earlier, the governing loading condition to be tested on the concrete boxes is a 27 kip point load. The point load represents a truck wheel. To stay consistent with current practices the box was tested at the same three critical points as in concrete slabs, that is, the center, edges and corners. Four total loading tests were done on the concrete box. One location in the center and corner were tested as well as two edges (due to non-symmetry in both directions.) Figure 13 displays these loading locations. Since the interior slits are perpendicular to the bottom edge, the lowest loading point is called perpendicular edge if the figure and future tables. The same idea is true for the parallel slit to the right edge.

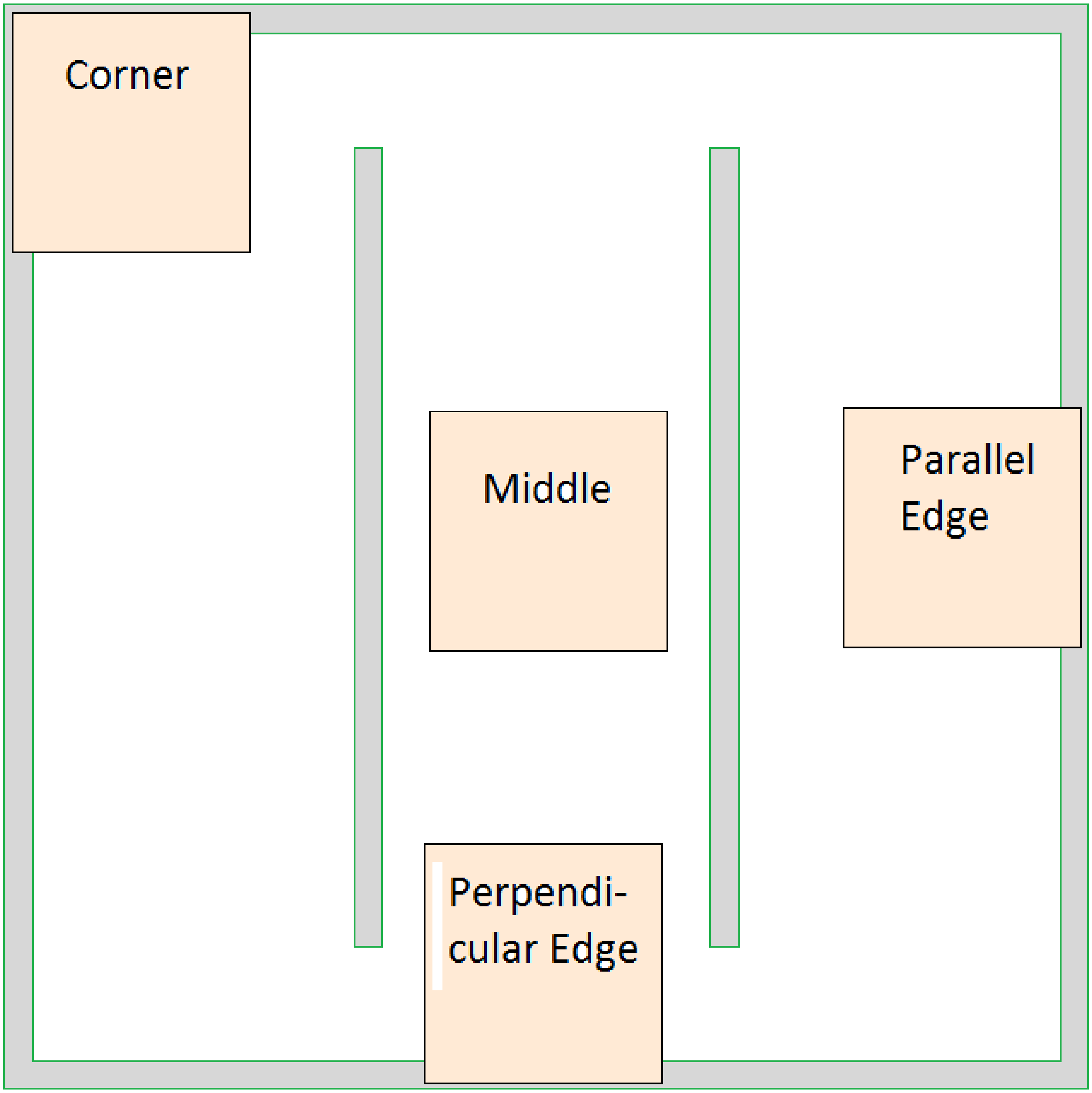

Figure 13: Load locations for testing of box

In order to get accurate loading of the concrete box a redundant system was used. First the hydraulic ram used to apply the 27 kip load has gauges and dials on it that tell how much force is being applied. Figure 14 shows the set-up of the hydraulic ram that applies the 27 kip load. The ram is mounted below a very sturdy steel frame that can withstand a one million pound point load in any location.

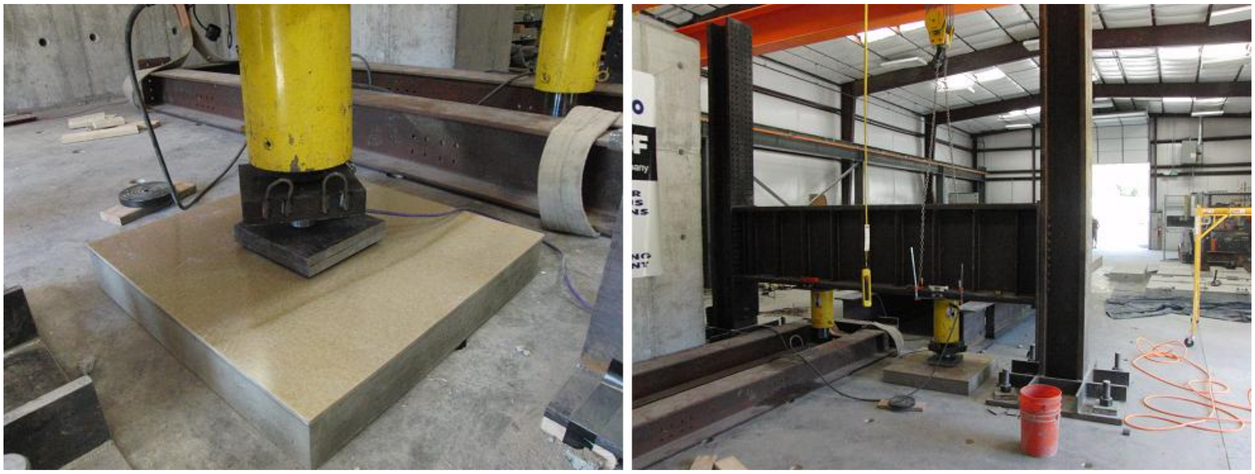

Figure 14: Set-up of box testing site

The second redundancy is computer data acquisition recorded with the Vishay System: Model 5100B. The Vishay system can record accurate measurements with a variety of devices including: string potrometers, strain gages, tiltmeters, and loading cells. Figure 15 shows what the Vishay system looks like along with the loading cell used during testing. (The left picture also gives a good look at the fiberglass lid.) With this a loading cell was placed between hydraulic ram and the concrete box with steel plates underneath to correctly distribute the load. This load cell, through the Vishay system, recorded the force on the box as a set of time/load data. This data could then be analyzed subsequently.

Figure 15: Load cell and Vishay system

Results

The data for this section was obtained using the concrete testing machine (Forney Fx 600) in the USU concrete lab and data acquisition hardware (Vishay System 5100B) in the USU SMASH lab.

Slump

For this project an official slump test was never actually done. This is because it was more important to have the concrete fit into the wooden forms smoothly. As the first batch did fit into the small 'practice' wood frame it didn't seem necessary to do a slump test. However, the estimated slump of the mixes was about 4 to 6 inches based on past experience.

Compressive Strength

The following table shows the crushing loads placed on the concrete cylinders. 14-day tests were done on Batch B through E in order to predict the strengths of the concrete and allow construction of the first set of concrete boxes. There is also a distinction in the table between

Compressive Strength Test Results

Cylider Area = 12.566 in^2

62832 lbs required for 5000 psi strength.

Batch	14-day Load (lbs)	Crushing Load (lbs)	Crushing Load (psi)	Fracture Type & Comments:
A	-	41940	3337	Crushing at top only
Af	-	48020	3821	"
B	45545	60765	4836	Crushing at top only
Bf	50655	63750	5073	"
C	39205	56285	4479	Crushing at top only
Cf	40875	50465	4016	Columnar crack
D	40100	52450	4174	Little cruching at top
Df	32235	49670	3953	"
E	69595	87280	6946	Cone fracture
Ef	73615	87700	6979	Columnar crack

None: The 'f' in the Batch column indicates a mix with plastic fibers.

Table 2

concrete with and without plastic fibers. Table 2 displays the compressive loads attained during all cylinder tests. It also states the way each cylinder failed.

It is interesting to note first off that Batch C and D did not reach the 5000 psi strength. It seems the reasons for this go back to what was said in the design process. Even though gravel is the strongest part of the concrete mix it is the amount of cement in the mix that determines the overall strength. Batch B with fibers does reach 5000 psi. Batch E, as expected, has the highest strengths of almost 7000 psi due to the lower w/c ratio.

Table 2 indicates that most of the cylinders tested had crushing at the top. Most of these crushing failures looked very similar to that show on the right in Figure 16. The cylinder from Batch D is shown in the center picture in Figure16. It is likely that this small amount of breaking in the failure indicates that the concrete was not properly set up. The exposed concrete did seem moist to the touch and this is not surprising because Batch D was the high slump design batch with extra water added. The left picture in Figure 16 is a columnar crack failure from Batch Ef (high w/c with fibers.) A columnar crack is better than random crushing and it shows because cylinder "Ef" had the highest strength of near 7000 psi.

Figure 16: Crushing failures in concrete cylinders

Relation between Concrete with or without Plastic Fibers

Plastic fibers were added in the mix design as to provide additional strength for the concrete mix. Table 3 shows how much additional strength was gained by adding fibers.

Effect of Plastic Fibers on Strength			
	Crushing Load (psi)		
Batch	Regular	w/ Fibers	% Increase
A	3337	3821	14.50
B	4836	5073	4.91
C	4479	4016	-10.34
D	4174	3953	-5.30
E	6946	6979	0.48

Table 3

As seen Batch C and D did not behave as predicted actually having decreased strength when plastic fibers were added. This is possibly just bad data that cannot be checked because only two cylinders were casted. However, the strange design values of 0.65 aggregate ratio and 600 lbs/yd^3 water are not recommended in the design tables. So maybe the concrete behaves abnormally outside the recommended ranges. It is worth noting that the increase in strength from adding plastic fibers is greater with the 14-day tests. Only Batch D showed a decrease in strength and Batch E had a much greater increase of 5.8%.

Compressive Strength in Final Application

While testing the concrete box in the four designated locations the box was always able to withstand the load. An initial test was done (not to the full load) just to make sure the equipment was all working correctly. Figure 17 shows the loading curves of the four test locations and Table 4 relates the peak loads taken from the graphs.

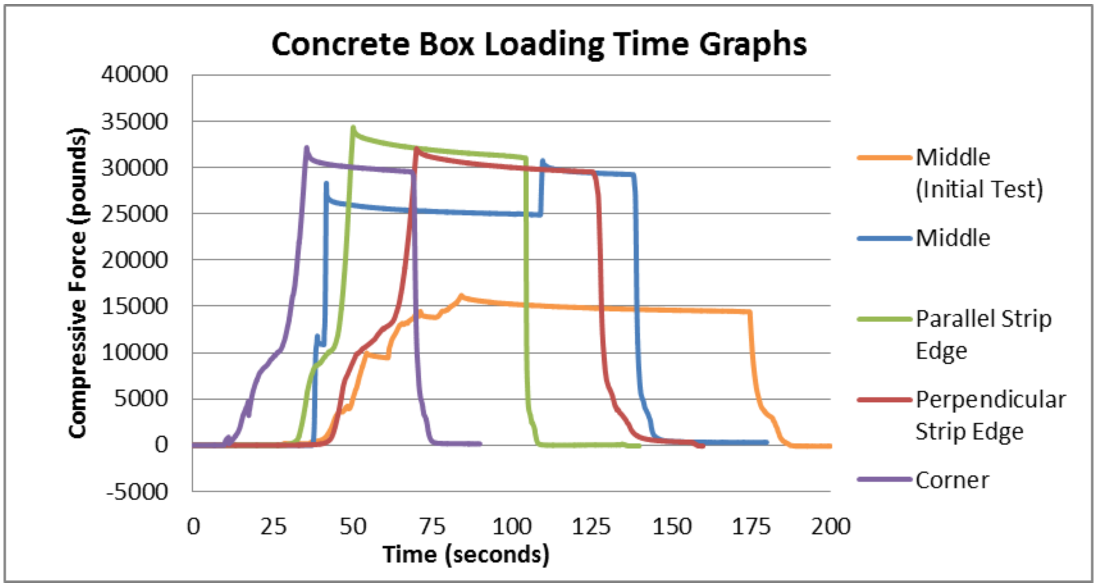

Figure 17

Maximum Atained Load	
Load Location	Maximum Load (kips)
Middle (Initial)	16.19
Middle	30.77
Parallel Edge	34.36
Perpendicular Edge	32.04
Corner	32.18

Table 4

After the initial practice test done there was some discrepancy between the pump gage and the Vishay system. It is probable that the Vishay data was more accurate but it was decided to increase the load during testing just to be safe. In all the loading graphs you can see a slight concave curve coming down from the peak load. This is actually the hydraulic pump loosing force. It was intended to place the 27 kip load and leave it for a few seconds so increasing the initial load actually guarantees the 27 kip load to stay in place.

During the loading of the concrete box some cracks did show up on it, especially during the edge loads. There were several cracks in the bottom of the box along with one large crack on the perpendicular edge. The pictures in Figure 18 show the crack forming off one of the strips. This crack measures 0.03 inches at the base. Also on the bottom the crack continues along the side of the slit quite a ways.

Figure 18: Perpendicular crack

Figure 19: Parallel crack

Figure 19 shows a smaller crack on the parallel edge of the box with its extension along the base. This crack, as seen, did not propagate as far nor as wide.

The corner underneath the corner loading point showed some crushing at the base during testing. It does seem that the crushing is due to an uneven base which was due to the fabrication after the concrete mixing. This corner crushing is shown in Figure 20.

Figure 20: Corner crushing

Finally, some of the cracking over the entire base part of the box can be seen in Figure 21. The vertical crack in the left side of the figure is the same as seen in the right side of Figure 18. The larges crack again is the one from Figure 18 with six distinct smaller cracks over the rest of the bottom of the box. During testing the fiberglass lid did deflect slightly but it did withstand the loading completely. The most deflection was seen at the corner loading location.

Figure 21: Bottom plane cracking

Discussion, Recommendation, Conclusions

The goal of designing and building a concrete box to withstand roadway loading conditions seems to have been a partial success. The cracking seen means that the box would not be waterproof therefore leaving the electronic equipment liable to corrosion. Despite this the box did remain structurally intact for an average 32 kip load in four locations. There would be questions as to whether the box would stay intact over years of cyclic loading. This mainly depends how the charging system would be implemented. Traffic loads would make a lot of sharp peak stresses if there was a crack in the road surface from installation. Because of this it may be necessary to repave the entire road surface during installation to prevent the box from cracking over time. As far as constant loads, the 32 kip loads were placed for at least 30 seconds. Even a continuous 27 kip load that might occur during a traffic jam is not as demanding.

The real question for evaluation is why did the box crack? Even though it was sought, a perfectly plane concrete surface was not achieved on the bottom of the box. It was difficult because the wood frame extended higher than the box was intended to. Upon close inspection it appeared that the bottom of the concrete box was slightly convex except for the corners which stuck out a bit further than the average plane of the surface. When testing, the box was placed on perfectly flat concrete slab. Therefore only the most protruding points of the concrete box were touching the floor (i.e. the corners and center) which causes very high stress at the point of contact. Because of this configuration during testing the biggest crack parallel to the slip in the middle and the crushing in the corner seem to be mostly due these high stresses. There were still many cracks on the bottom of the concrete box which may or may not have been due to these differential stresses.

When the concrete box is actually employed in the roadway it can be placed on borrow or gravel thus eliminating the points of high stresses because a the surface would not be so flat like the bottom slab of the box. This will likely eliminate most of the cracking in the box but a precautionary solution to these problems would be in a slight design change. The sides of the wood forms should be made to the correct depth of the box in order to strike off the concrete and make a flatter surface. The bottom of the box should be made at least a quarter inch thicker to help prevent some of the cracking on the bottom if that problem is persistent. However, making the bottom too thick will increase the weight to the point of disallowing easy installation. Lastly decreasing the water-cement ratio a bit more will make the concrete slightly stronger which will also help avoid cracks.

These modifications to the design are redundant by solving the same problems twice but that is the point. It is not completely clear why the cracks occur but the adjustments should be sufficient to ensure the final product is satisfactory. From the cylinder tests with a w/c ratio of 0.45 which had a compressive strength of 7000 psi, it can be assumed that a mix design similar to this would be strong enough for the box to withstand cracking. Also, in the initial test the fiberglass lid did work well by holding up under the loadings without cracking. The redesigned concrete box would function properly in final application to protect the electrical charging equipment and keep water out. With this the product proposal is complete.

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Appendix A

Test Batch Design Tables

Mix Design:	Batch	A	Baseline Design		
Mixing water estimate (Table 1)			Mix design size =	27	ft3
Water =	425	lbs/yd3	Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)			Gravel recalc. =	88.5	lbs/ft
w/c =	0.57		Concrete weight =	3800	lbs/yd3
Cement =	745.6	lbs/yd3	Plastic fibers =	1.55	lbs/bag
Coarse aggregate fraction (Table 3)					
Fraction =	0.50		Batch size =	0.12	ft3
Aggregate:	13.5	ft3			
Gravel =	1282.5	lbs/yd3	Component Weight:		
Fine aggregate difference			Water =	1.89	lbs
Sand =	1346.9	lbs/yd3	Cement =	3.31	lbs
Plastic fibers calculation			Gravel =	5.70	lbs
1 bag for 1 cubic yard concrete			Sand =	5.99	lbs
Fibers =	0.0069	lbs/yd3	Fibers =	0.007	lbs

Mix Design:	Batch	B	Corrected Aggregate Density		
Mixing water estimate (Table 1)			Mix design size =	27	ft3
Water =	500	lbs/yd3	Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)			Gravel recalc. =	88.5	lbs/ft
w/c =	0.57		Concrete weight =	3800	lbs/yd3
Cement =	877.2	lbs/yd3	Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)					
Fraction =	0.50		Batch size =	0.145	ft3
Aggregate:	13.5	ft3			
Gravel =	1194.8	lbs/yd3	Component Weight:		
Fine aggregate difference			Water =	2.69	lbs
Sand =	1228.1	lbs/yd3	Cement =	4.71	lbs
Plastic fibers calculation			Gravel =	6.42	lbs
1 bag for 1 cubic yard concrete			Sand =	6.60	lbs
Fibers =	0.0081	lbs/yd3	Fibers =	0.008	lbs

Mix Design:	Batch	C	Extra Gravel and Fibers			
Mixing water estimate (Table 1)				Mix design size =	27	ft3
Water =	500	lbs/yd3		Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)				Gravel recalc. =	88.5	lbs/ft
w/c =	0.57			Concrete weight =	3800	lbs/yd3
Cement =	877.2	lbs/yd3		Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)						
Fraction =	0.65			Batch size =	0.14	ft3
Aggregate:	17.55	ft3				
Gravel =	1553.2	lbs/yd3		Component Weight:		
Fine aggregate difference				Water =	2.59	lbs
Sand =	869.6	lbs/yd3		Cement =	4.55	lbs
Plastic fibers calculation				Gravel =	8.05	lbs
1 bag for 1 cubic yard concrete				Sand =	4.51	lbs
Fibers =	0.0079	lbs/yd3		Fibers =	0.016	lbs

Mix Design:	Batch	D	Greater Slump and Fibers			
Mixing water estimate (Table 1)				Mix design size =	27	ft3
Water =	600	lbs/yd3		Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)				Gravel recalc. =	88.5	lbs/ft
w/c =	0.57			Concrete weight =	3800	lbs/yd3
Cement =	1052.6	lbs/yd3		Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)						
Fraction =	0.50			Batch size =	0.145	ft3
Aggregate:	13.5	ft3				
Gravel =	1194.8	lbs/yd3		Component Weight:		
Fine aggregate difference				Water =	3.22	lbs
Sand =	952.6	lbs/yd3		Cement =	5.65	lbs
Plastic fibers calculation				Gravel =	6.42	lbs
1 bag for 1 cubic yard concrete				Sand =	5.12	lbs
Fibers =	0.0081	lbs/yd3		Fibers =	0.016	lbs

Mix Design:	Batch	E	Higher w/c Ratio			
Mixing water estimate (Table 1)				Mix design size =	27	ft3
Water =	500	lbs/yd3		Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)				Gravel recalc. =	88.5	lbs/ft
w/c =	0.45			Concrete weight =	3800	lbs/yd3
Cement =	1111.1	lbs/yd3		Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)						
Fraction =	0.50			Batch size =	0.145	ft3
Aggregate:	13.5	ft3				
Gravel =	1194.8	lbs/yd3		Component Weight:		
Fine aggregate difference				Water =	2.69	lbs
Sand =	994.1	lbs/yd3		Cement =	5.97	lbs
Plastic fibers calculation				Gravel =	6.42	lbs
1 bag for 1 cubic yard concrete				Sand =	5.34	lbs
Fibers =	0.0081	lbs/yd3		Fibers =	0.016	lbs

Form Batch Design Tables

Mix Design:	Batch	F	Form Batch 1			
Mixing water estimate (Table 1)				Mix design size =	27	ft3
Water =	500	lbs/yd3		Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)				Gravel recalc. =	88.5	lbs/ft
w/c =	0.55			Concrete weight =	3800	lbs/yd3
Cement =	909.1	lbs/yd3		Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)						
Fraction =	0.50			Batch size =	1.45	ft3
Aggregate:	13.5	ft3				
Gravel =	1194.8	lbs/yd3		Component Weight:		
Fine aggregate difference				Water =	26.85	lbs
Sand =	1196.2	lbs/yd3		Cement =	48.82	lbs
Plastic fibers calculation				Gravel =	64.16	lbs
1 bag for 1 cubic yard concrete				Sand =	64.24	lbs
Fibers =	0.0814	lbs/yd3		Fibers =	0.081	lbs

Mix Design:	Batch	G	Form Batch 2			
Mixing water estimate (Table 1)				Mix design size =	27	ft3
Water =	500	lbs/yd3		Gravel density =	95	lbs/ft
Water -cement ratio (Table 2)				Gravel recalc. =	88.5	lbs/ft
w/c =	0.5			Concrete weight =	3800	lbs/yd3
Cement =	1000.0	lbs/yd3		Plastic fibers =	1.515	lbs/bag
Coarse aggregate fraction (Table 3)						
Fraction =	0.50			Batch size =	1.85	ft3
Aggregate:	13.5	ft3				
Gravel =	1194.8	lbs/yd3		Component Weight:		
Fine aggregate difference				Water =	34.26	lbs
Sand =	1105.3	lbs/yd3		Cement =	68.52	lbs
Plastic fibers calculation				Gravel =	81.86	lbs
1 bag for 1 cubic yard concrete				Sand =	75.73	lbs
Fibers =	0.1038	lbs/yd3		Fibers =	0.104	lbs