SELF-CONSOLIDATING CONCRETE—
APPLICATIONS FOR SLIP FORM PAVING

Pooled Fund Project

Problem Statement
December 2003

PROJECT TITLE

Self-consolidating Concrete—Applications for Slip Form Paving

PROJECT GOAL

The goal of the proposed research is to develop a new type of self-consolidating concrete (SCC) for slip form paving. It is envisioned that SCC will produce more workable concrete and smoother pavements, better consolidation of the plastic concrete, and higher rates of production. Specific objectives include the following:

- Simulate the slip form paving process in the laboratory
- Explore test methods that can appropriately measure the characteristics of slip form SCC
- Form a better understanding of the plastic behavior of current slip form concrete
- Investigate essential paste material components (such as superplasticizer, viscosity modifying agent (VMA), mineral filler, and other new admixtures) and their roles in slip form SCC
- Study the effects of particle packing and orientation on properties of slip form SCC
- Develop mix design methodology, acceptance criteria, and mix proportions for slip form SCC
- Conduct preliminary field investigation for new slip form SCC mixes
- Evaluate properties of field slip form SCC
- Monitor performance

The project will begin with a feasibility study to determine whether subsequent phases will be conducted. A technical advisory committee (TAC) will be formed from participants on the project. The TAC will guide the project and make the decision whether or not to proceed past the feasibility phase.

PROJECT DESCRIPTION AND BACKGROUND

Slip form paving has been extensively used by the worldwide paving industry since its development in Iowa in the 1940s. Different from fixed form paving, slip form paving brings together concrete placing, casting, consolidation, and finishing into one unique process. In this paving process, a concrete mixture with a slump of less than 2 inches is placed in front of a paver. As the paver moves forward, the mixture is spread, leveled, consolidated (by equally spaced internal vibrators), and then extruded. After extrusion, the fresh concrete slab can hold its shape for further surface finishing, texturing, and curing until the concrete sets. The mixture's low consistency requires a great deal of vibration to move entrapped air and consolidate the concrete.

In finished PCC pavements, over-consolidation may occur if the mix is not properly designed. Over-consolidation is noted when longitudinal trails can be visually observed in the surface.

These "vibrator trails" run parallel to each other with spacing similar to that of the vibrators on pavers. Cores taken from vibrator trails have revealed many instances where the hardened concrete contains less than 3% air, rather than 6%–7% as designed, thus significantly reducing concrete freeze-thaw durability (*1*). Although measures can be taken to monitor the frequency of vibrations, vibrations are still inevitable. It would be a revolutionary advancement in paving technology if the vibration of pavement concrete could be eliminated.

In addition, concrete paving crews in the field tend to deposit large piles of stiff concrete in front of the paving machine. Vibration and "bulldozing" by the paving machine are relied upon to level the pile and move concrete laterally on the subgrade. The paving machine often floats up on the concrete piles, creating undulations in the finished surface, thereby reducing the smoothness and rideability of the pavements. Pavement smoothness is a key factor in determining highway user satisfaction. In 1996, the Federal Highway Administration (FHWA) commissioned a national survey of frequent highway users that asked questions about what they wanted in their highway "product." The public very clearly stated that road condition was their top priority, followed by safety and reduction of congestion. Research has shown that smooth roads cost highway agencies less over the life of the pavement, resulting in decreased highway user operating costs. The FHWA has set a performance goal to significantly improve the quality of measured pavement smoothness of the National Highway System by 2008 (*2*). More and more state DOTs are implementing smoothness and rideability requirements as pay factors in highway construction contracts. As a result, there is great interest in a more workable concrete that would reduce the tendency to float the paver and produce smoother pavements.

Today's concrete research and practice has shown that material selection and mix design of concrete can be tailored to provide good compaction without the need for vibration. This approach is based on the principles of self-consolidating concrete widely used in precast and cast-in-place construction. SCC has generated tremendous industrial interest since its initial introduction in Japan in the 1990s. Due to its excellent flowability and stability (segregation resistance), SCC has been used for many different applications, including bridge decks, precast bridge members, and pavement repairs. SCC can be cast and compacted in small dimension and/or heavily reinforced formwork without vibration. Use of SCC technology also increases the speed of the construction, improves the quality of the concrete (without segregation and loss of air), and reduces the cost of labor, energy, and environmental impacts caused by vibration and/or noise.

A challenge in developing SCC for slip form paving is that the new self-consolidating concrete needs to possess not only excellent self-compactibility and stability before extrusion but also sufficient strength right after extrusion while the concrete is still in a plastic ("green") state. This "green" strength will ensure that the fresh concrete can sustain its self-weight, or hold the slab shape, without having support from any framework. It is understood that to obtain self-compaction, a concrete mixture needs to overcome the shear strength resulting primarily from particle friction and cohesion; but also, in order to hold the slab shape the fresh concrete must gain enough shear strength quickly. A key issue is achieving these two conflicting needs for SCC at the appropriate time.

Concrete is a "shear-thin" material. At a high shear rate (such as during mixing), concrete microstructure is disturbed, and its yield stress and viscosity are reduced. Thus, the concrete becomes more flowable and self-compactable. While at a low (or zero) shear rate, concrete microstructure can be re-built, "green" strength will develop, and the concrete will become less deformable. The extrusion process, even at a low pressure, will help concrete consolidation and "green" strength development by rearranging solid particles for packing. Based on the current knowledge of concrete materials, the project investigators believe that a rational balance between compactibility and the "green" strength of a concrete mixture may be achieved by tailoring the concrete materials and mix design. Therefore, great potential exists for the development of a desirable SCC for slip form paving. The new slip form SCC may not be as fluid as the conventional SCC, but it would (1) be workable enough for machine placement, (2) be self-consolidating without segregation, (3) hold its shape after extrusion from a paver, (4) have the required short-term strength gain and satisfactory texture characteristics, and (5) have comparable performance properties (strength and durability) to current pavement concrete.

A collaborative research team has been formed for this proposed research. The team consists of members from the Center for Portland Cement Concrete Pavement Technology (PCC Center) at Iowa State University (ISU), and the Center for Advanced Cement-Based Materials (ACBM) at Northwestern University (NU). The PCC Center has a rich experience in concrete materials, pavement system design, and construction, and will take the lead in this project. ACBM is a national leader in the development of SCC and concrete extrusion technology, and will provide input on testing, modeling, and mix design of SCC. A technical advisory committee (TAC) will be formed to keep the project well grounded with an industry perspective. The committee will consist of experts from state departments of transportation (DOTs), the FHWA, and the concrete industry. It is believed that this dynamic research team will offer all the experience and expertise necessary for the successful development of slip form SCC.

RESEARCH PLAN

The proposed research will have four phases: (1) feasibility study, (2) lab study on mix design of slip form SCC, (3) field investigation of slip form SCC paving and final project report preparation, and (4) performance monitoring.

Phase 1: Feasibility Study

Task 1.1: Form a technical advisory committee for the project and collect industrial inputs on the new development

The project would start with a small-scale workshop (20–30 people) on SCC technology. In the workshop, effort will be made to include industrial issues in the final design of the development work. Information will be gathered from selected workshop participants, including paver manufacturers, concrete producers, concrete paving contractors, and agency personnel. Following the workshop, a technical advisory committee consisting of representatives from state DOTs, the FHWA, and the concrete industry will be formed. All project sponsors will be invited to participate in the TAC.

The TAC will meet approximately every six months to review the project's progress and to advise on subsequent work. This will serve to keep the project well grounded with a practical, industry perspective, as well as keep the project on track through periodic review.

This process of industry inclusion becomes critical during the most important phase of the project—technology transfer. By involving industry representatives in the project from the beginning, and by getting their feedback into the design and implementation of the project program, the task of getting their "buy in" for the use of the developed technology is greatly enhanced.

The PCC Center will work closely with ACBM on this task. ACBM was founded in 1989 as a National Science Foundation Science and Technology Center; in 2000 it became an independent center, funded entirely by industry donations. ACBM currently has 18 industrial partners that represent a broad spectrum of the cement and concrete business, giving the center a unique position to attract industry involvement in this project. ACBM conducted a very successful workshop on SCC in November 2002.

Task 1.2: Simulate the slip form paving process in the laboratory

In order to evaluate fresh concrete properties for the slip form paving application, a laboratory simulation of the slip form operation is necessary. The lab simulation is to provide insight into the energy needed for proper compaction of the slip form pavement concrete as well as into the relationship between the degree of compaction (generally described as density) and other concrete properties, such as air content and "green" strength. Different simulation tests will be performed at the PCC Center and ACBM. The same materials and mix proportions will be used by both centers, and the test results will be compared.

Slip form paving simulation at the PCC Center

Over 15 years ago, the Iowa DOT developed a "Vibra John" device simulating slip form pavement concrete and evaluating the concrete flow property. The "Vibra John" device is actually an L-box with a vertical leg of 12"x12"x12" and a horizontal leg of 12"x 4"x18". It is similar to today's L-box for conventional SCC flow testing and has a sliding door between the vertical and horizontal legs. In the original test, the vertical leg is filled with a concrete mixture, and an internal vibrator is inserted into the fresh concrete for proper vibration. After vibration, the sliding door between the vertical and horizontal legs is opened, and the concrete flows (or is extruded) into the horizontal leg due to self-weight. The flowability of the concrete is determined by the length of time for the mixture to travel into the horizontal leg.

In the proposed research, the ISU investigators will use the "Vibra John" device to study current slip form concrete and new slip form SCC mixes. The original vibrator will be used only for current slip form concrete mixes, and no vibration (but maybe a low pressure) will be applied on new slip form SCC mixtures. After concrete is extruded and the horizontal leg is filled, cores will be taken, and the fresh concrete properties—such as density, air content, and "green" strength—will be tested. (Note that careful sample handling is important during the tests.) The potential slip form SCC mixes may have similar properties to that of the current slip form concrete, and they will be further studied in the next phase.

Slip form paving simulation at ACBM

Three laboratory methods (described below) will be use to determine the relationship between the energy applied for compaction and the degree of compaction (density) of the fresh concrete. Once this relationship is understood, samples from a pavement construction site will be tested for density. From the compaction energy–concrete density relationship developed in the laboratory, it will be possible to determine the compaction energy used to produce the field samples. Field trials will be performed to calibrate the three test methods. These tests will also make possible the comparison of the effects of various mix design and material parameters on the compaction of the fresh concrete.

Method One is based on a piece of equipment developed for the evaluation of no-slump concrete (*3*). Similar to the gyratory compactor used for asphalt concrete, the equipment applies pressure and circular motion on fresh concrete simultaneously (see Figure 1).

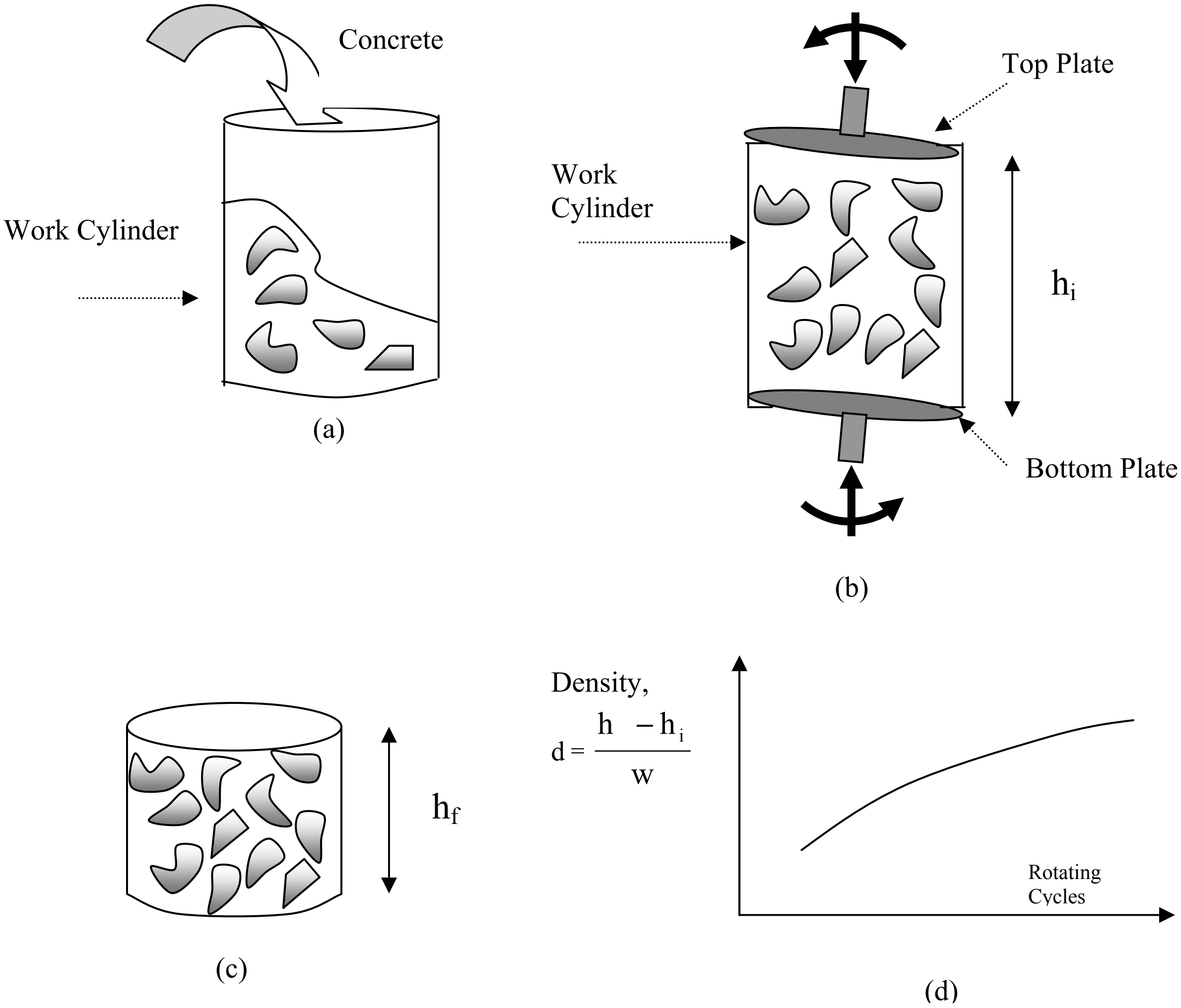
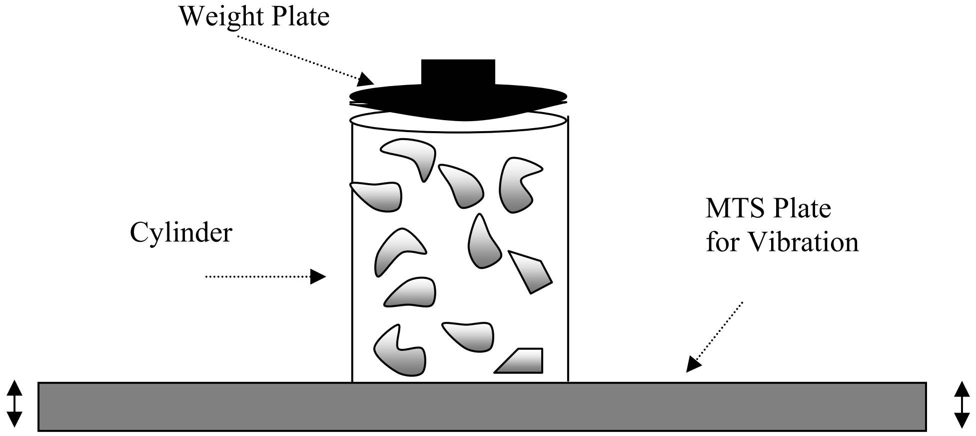


Figure 1: (a) Pouring concrete of known weight (w) into the work cylinder. (b) Compacting and squeezing the air out of the concrete by compressive and rotational motion of the top and bottom plates. The initial height, h_I, will decrease during the compaction. (c) Compacted sample after the test. The final height, h_f, will be smaller than h_i. (d) Test result showing the relationship between compaction force (rotation cycles) and concrete density.

First, a sample of concrete of known weight is placed in a work cylinder (Figure 1a). Parallel plates at the top and bottom of the cylinder rotate and compress the fresh concrete at the same time (Figure 1b). The plates remain parallel, but the angle between the plates and the work cylinder change during the circular motion. The fresh concrete inside the cylinder moves along the shear planes. This shear motion, together with compressive force, promotes particle alignment and forces air out of the concrete sample. The height of the concrete will be measured continuously during compaction. The density of the concrete during the test can be calculated by the measured height and the known weight of the sample. After the test is completed, the sample can be removed for further evaluation (Figure 1c). It will be possible to vary the compaction pressure and the compaction cycles by programming the control unit of the test machine. The test will provide a report showing the density of the sample (degree of compaction) versus the rotation cycles (force needed for compaction) (Figure 1d).

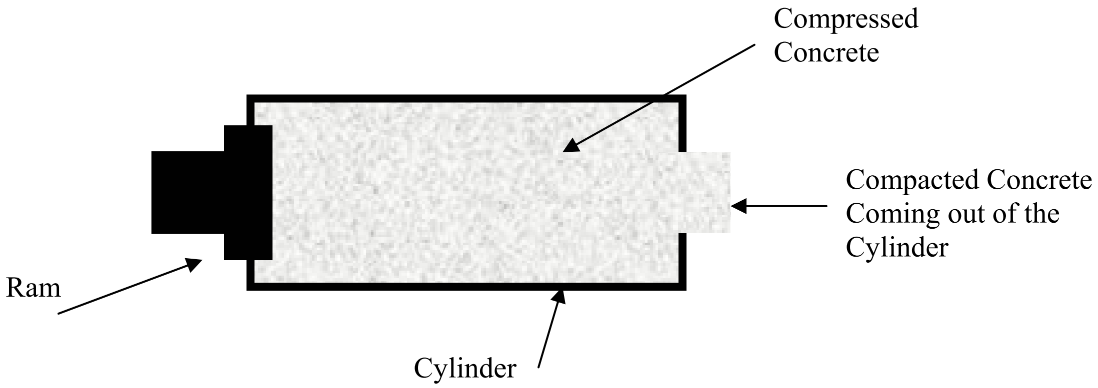
Method Two will simulate the slip form vibration and compaction of fresh concrete in the laboratory by using an MTS testing machine. Fresh concrete of known weight will be placed inside a cylinder (which sits on a vibrating plate), and a weight plate will be placed on top of the sample (Figure 1e). By using an MTS machine, it will be possible to control the frequency and amplitude of the vibrating plate. The MTS plate will generate the vibration, and the weight plate will provide compressive force at the top of the cylinder. The air will be forced out and the fresh concrete will be compacted. As described in **Method One**, the density before and after compaction will be calculated and plotted against compaction energy. The energy used for compaction will depend on the time of compaction, frequency of the vibration, and the weight of the top plate.



(e)

Figure 1: (e) Vibration and compaction using MTS equipment

Method Three will produce fresh concrete specimens by an extrusion process using compressive and shear forces that simulate low pressure concrete paving. Fresh concrete will be placed in a cylinder. The concrete will then be compacted by a ram (Figure 1f). The compacted specimen will come out of the smaller opening at the end of the cylinder. The force needed for compaction will be determined. By using different opening diameters at the end of the cylinder, the compaction of the concrete and the resulting density of the sample can be changed.



(f)

Figure 1: (f) Molding of concrete

All of the proposed laboratory methods will provide information about the relationship between the energy needed for compaction and the compaction degree (density) of the fresh concrete. These laboratory trials will then be compared to field samples to establish a correlation between laboratory simulation and actual field practice.

Field trials will consist of taking samples from pavement construction sites to determine the density of the fresh concrete before and after vibration used in the slip form paving operation. The energy needed for this compaction will be determined from the compaction energy–density relationship developed in the laboratory. The goal will be to evaluate the effect of material parameters on the compaction of concrete and to eliminate the need for vibration by developing concrete mixes that use the principles of self-consolidation. The density of the concrete after slip form paver vibration will be compared with the density of the SCC mix designs developed in the laboratory to test whether the desired density is achieved.

Task 1.3: Explore test methods that can appropriately measure characteristics of slip form SCC

Key properties of slip form SCC may include flow property, stability, compactibility, and "green strength" of fresh concrete. The test methods that appropriately measure the properties should be defined.

Slip form SCC requires certain workability for machine placement. The workability, greatly related to concrete flow property, needs to be evaluated. The flow property of concrete has been extensively studied since development of SCC. A great amount of work on this subject has been done at ACBM. Research has indicated that almost all aspects of concrete will influence concrete flow property, including (1) aggregate characteristics (grading, particle shape, orientation, and surface texture), (2) cementitious material characteristics (chemistry, fineness, shape, and surface texture), (3) chemical admixtures (superplasticizer, VMA, and air entraining agent [AEA]), (4) mix proportions (especially aggregate content and mortar matrix fraction), (5) mixing rate and level of vibration, and (6) environmental conditions that influence rate of cement hydration. Different equipment and techniques have been developed to measure concrete flow property. However, few techniques are suitable for characterizing flow property of low slump pavement concrete. Research on the flow property of pavement concrete is currently being conducted using the vibration slope apparatus (VSA) at the PCC lab at ISU. Together with the "Vibra John" device, VSA will be used in the proposed study. ACBM will use the center's available rheometer and L-box device to study the flowability of paste and concrete, respectively.

Stability defines the ability of a SCC mixture to retain a uniform distribution of all constituent materials once the concrete is in place. Instability can occur in various forms such as bleeding, coarse aggregate settlement, and blocking during flow. The causes of instability vary from raw material characteristics and mixture proportions to rebar configurations, drop heights, and pumping pressures (*4*). If a mixture is statically unstable, the heaviest materials sink and the lightest materials rise. In normal weight concrete the two lightest materials are air and water. The movement of air and water in fresh concrete can result in higher permeability in the near-surface layer concrete and a weak bond of the concrete to the reinforcing steel. Some non-standard test methods have been developed to evaluate the stability of SCC, including surface settlement, penetration apparatus, L-box, U-box, and J-ring tests (*5, 6, 7, 8*). In this project, the surface settlement test and penetration apparatus test will be investigated at ISU and NU, respectively. CT scan tests to be performed at ISU (see Task 2.2) will also provide information on concrete stability.

Compactibility of SCC describes how well concrete can be compacted, and it can be simply evaluated from density or unit weight of the fresh concrete. For given aggregate type and gradation, the dry rodded unit weight (DRUW) of the aggregate is almost constant, and the density of its SCC mainly depends on paste density and content (or paste fraction). The difference in density between aggregate and paste of SCC is a control factor of concrete stability (segregation resistance). The smaller the difference is, the higher the segregation resistance. ISU proposes to use the unit weight test and CT scan (see Task 2.2) for evaluation of slip form SCC.

“Green” strength of SCC may be estimated from a modified compression test. A 4-inch diameter core will be taken from the fresh concrete after “Vibra John” tests. The core will be wrapped with a thin, soft rubber sheet to provide the concrete with some lateral confinement. Then the sample will be compressed uniaxially until a specified excessive deformation occurs. Ouldhammou et al. (*9*) studied mechanical properties of fresh concrete subjected to biaxial compression forces in drained and undrained conditions, with confinement stresses ranging from 12 to 400 KPa (2–58 psi), at different times after casting. They found that the internal friction characteristic was independent of time for lateral confining stress larger than 130 KPa (18 psi), cohesion was very small compared to obtained maximum stresses, and the Young’s modulus (related to concrete stiffness) increased with time. (Modified tri-axial tests for fresh concrete may be tried at the ISU soil lab depending on suitability and availability of the equipment.)

In addition to the above tests, general concrete property tests, such as standard compressive/flexible strength tests and air void characterization, will also be performed to ensure that the new SCC mixes meet general pavement performance requirements.

Table 1 summarizes the proposed tests for the research to characterize slip form SCC. The results from the PCC Center and ACBM will be compared and the appropriate test methods will be defined and selected for further study.

Table 1. Proposed test methods for properties of fresh slip form SCC

Concrete property	Tests to be performed at ISU	Tests to be performed at NU
1. Flowability	VSA and “Vibra John” device	Rheometer (paste) and L-box (concrete)
2. Stability	Surface settlement	Penetration apparatus
3. Compactibility	Density test and CT scan	Gyration compactor, cylinder (Figure 1)
4. “Green” strength	Modified compression test	MTS
5. Hardened SCC	ASTM tests for strength and air	Strength, air, and drying shrinkage

Task 1.4: Study fresh concrete properties of current slip form concrete

The investigators believe that greater understanding of the material properties of the current slip form concrete will provide the research team with insight into the development of new slip form SCC. It is proposed that flow property (mortar rheology), compactibility (density and aggregate arrangement), and "green" strength tests will be done for existing slip form concrete, and the results from the current Iowa slip form concrete will be compared with those from conventional SCC. Based on analysis of the results, suggestions for modifications of slip form concrete mix proportions will be proposed.

Task 1.5: Investigate essential material components and potential mix proportions of slip form SCC

As discussed before, concrete flow properties are significantly influenced by both aggregate and paste. The effects of aggregate on concrete flow properties are greatly related to aggregate shape, gradation, and content. Effects of paste on concrete flow properties are associated with the flow properties of paste, paste density, and paste content. Small spherical particles in cementitious materials, such as fly ash and silica fume, have small resistance to fluid flow, thus resulting in low viscosity or high flow ability in the paste. Silica fume is also used in SCC to reduce the difference in density between aggregate and paste, thus increasing concrete stability. However, due to fine particle size and high reactivity, silica fume often agglomerates in concrete without dispersion agents. Superplasticizer is therefore often used to disperse the agglomerated cementitious particles. Research has shown that overdose of superplasticizer often creases excess flow and lowers the stability of the concrete (*4*). As a result, VMA is commonly used in SCC to provide viscosity to the paste, preventing aggregate segregation. In addition, some mineral fillers (such as limestone powder) are also used in SCC as a dispersion agent and/or for increasing paste density. Clay materials are used to improve the concrete extrusion process. Although these basic roles of the paste components of SCC have been recognized, their contributions to "green" strength are not clear. This task is to investigate essential materials and the potential proportions that are needed for slip form SCC to provide sufficient flow and "green" strength during paving.

Task 1.6: Recommend testing method, mix design variables, and their ranges (or contents) of slip form SCC for Phase 2 study

Based on the information provided by Tasks 1.3 and 1.4, trial tests will be performed for selected mixes using equipment and test methods developed in Tasks 1.1 and 1.2. If some of the trial tests are promising (sufficient self-compactibility and "green" strength shown), a set of mix-design variables and their proportion ranges will be proposed for a Phase 2 study of slip form SCC. These variables may include different size and gradation of aggregate, different proportions of cementitious materials (portland cement, fly ash, silica fume, with or without limestone powder and clay), and different amount of superplasticizer and VMA.

The TAC will review the feasibility study and will determine whether or not to proceed with additional phases. If further study is warranted by the Phase 1 results, refined mix proportions will be determined in Phase 2.

Phase 2: Lab Study on Mix Design of Slip Form SCC

Phase 2 of the project will be conducted only if Phase 1 indicates that the concept of SCC technology in paving is feasible and that there is some certainty that further development will result in a successful product. The development efforts will be coordinated with FHWA Task 64, *Computer-Based Guidelines for Job-Specific Optimization of Paving Concrete.*

Task 2.1: Develop a statistical design of SCC mix proportion matrix for Phase 2 lab experiments

A mix design matrix will be developed using a statistical design method. The matrix will cover the types and ranges of material components of slip form SCC as proposed in Task 1.6. A rational minimum number of mixes will be selected from the matrix and tested to find out how the designed parameters influence the properties of slip form SCC.

Task 2.2: Study the effects of aggregate particle packing and orientation on properties of SCC

Research has revealed that the distance between aggregate surfaces dominates concrete particle packing, which has considerable influence on concrete flow properties. Factors such as aggregate size, shape, content, gradation, and coarse aggregate/total aggregate ratio affect the spacing between aggregate particles in concrete. “Green” strength of SCC provided by internal friction and cohesion also significantly depends on the aggregate (or paste) volume and particle arrangement/orientation. In this phase of the proposed research project, aggregate packing characteristics will be studied using x-ray computed tomography scanning (CT scanning).

X-ray CT scanning is a nondestructive technique for visualizing features in the interior of solid objects by obtaining digital information on their 3D geometry and properties. Components of the CT scanning system consist of a source and a detector, with the test specimen placed in between. In principle, CT scanning consists of measuring the attenuation of an x-ray beam from a number of different paths through the tested object and mathematically extracting the density of each point in a plane of the object. This 2D density map constitutes a CT slice that gives very accurate information within the plane. By creating several slices, a true 3D volumetric image of the object can be digitally built. CT scanning is highly sensitive to small density differences (<1%) between materials and has been proven for a wide range of materials including rock, soil, asphalt mixes, concrete, ceramics, and soft tissues.

X-ray CT scanning equipment is available at the Center for Nondestructive Evaluation (CNDE) at ISU. By using this technology, particle packing characteristics of current pavement concrete and newly developed SCC mixes will be studied and their effects on flowability, stability, and “green” strength of concrete will be investigated.

Task 2.3: Develop slip form SCC mix design methodology and acceptance criteria

One methodology for conventional SCC mix design is to divide concrete into two constituents: coarse aggregate and mortar. The rheology of the mortar is adjusted to achieve self-flowing concrete via incorporating a variety of mineral additives, plasticizers, and thickeners. This methodology can be modified by considering aggregate packing density and then be used for the present research.

ACBM has recently developed a rheological model that makes possible the close control of SCC properties through construction project changes in raw materials and climatic conditions. This model is a tool for mix design, choice of materials, and quality control, as well as for enabling further developments of admixtures and additives for SCC. The model is based on paste rheology criteria, which include minimum apparent viscosity, minimum flow-viscosity, and optimum flow-viscosity ratios to achieve SCC with satisfactory segregation resistance and deformability. The rheological criteria of the cement paste matrix are related to the average aggregate diameter and aggregate spacing, which are both influenced by the physical properties and total aggregate content of the concrete. The properties of SCC are characterized by quantitative measures of segregation and flow. These existing criteria will be modified, and new criteria on "green" strength of concrete will be established according to the preliminary information obtained from Phase 1.

Task 2.4: Investigate essential paste material components and their roles in slip form SCC concrete

Flowability, stability, compactibility, and "green" strength of slip form SCC will be evaluated for the minimum number of mixes proposed in Task 2.1, and the recommended test methods from the Phase 1 study will be used. The test results will be analyzed to reveal how and at what level the design variables affect the properties of slip form SCC. The results of the analysis may help in modifying and/or selecting mix proportion candidates for the field study in Phase 3.

Task 2.5: Recommend potential mix proportions of slip form SCC for field investigation

Based on the analysis of test data obtained from Task 2.4, potential mix proportions for slip form SSC will be selected and recommended for Phase 3 field investigation.

Phase 3: Field Investigation of Slip Form SCC Paving and Final Project Report Preparation

The following tasks will be conducted in Phase 3. Details for the tasks will be developed by the project investigators based on the results from Phases 1 and 2 and the inputs from the TAC members at the end of the Phase 2. Up to three test pavements will be constructed in this phase.

Task 3.1: Select construction time and location
Task 3.2: Establish primary guidelines for construction of slip form SCC, including modification of the existing slip form paver for the SCC paving
Task 3.3: Develop field test methods for data collection
Task 3.4: Perform field tests
Task 3.5: Analyze field test data
Task 3.6: Prepare final project report

The report will include an assessment of the potential cost benefit of the slip form SCC.

Phase 4: Performance Monitoring

In-service performance of the field demonstration sites will be monitored and documented in supplemental reports at 1, 3, 5, and 10 years. The pavement performance characteristics to be monitored and/or evaluated will include pavement surface condition (such as smoothness, cracking, and surface defects), concrete strength, air void characteristics, and structural integrity. Non-destructive evaluation (NDE) methods such as laser scanning and falling weight deflectometer (FWD) may be used in addition to visual examination. Cores may be taken from selected areas for strength and air void analysis.

RESEARCH TEAM

The collaborative research team formed for this proposed research includes Dr. Kejin Wang and Dr. David White from ISU and Dr. James Lingscheit and Dr. Surendra Shah from NU. The levels of PCC Center/ISU and ACBM/NU involvement in each task are shown in Table 2.

Table 2. Research tasks and team involvement

Phase/task	**PCC/ISU**	**ACBM/NU**
1.1: Form committee and conducting workshop	AAA	AAA
1.2: Simulate slip form paving in lab	AA	AAA
1.3: Explore test methods for slip form SCC	AAA	AAA
1.4: Study current slip form concrete	AAA	AAA
1.5: Investigate potential mix proportions	AAA	AAA
1.6: Recommend mixes and tests for Phase 2 study	AAA	AAA
2.1: Design SCC mix proportion matrix	AAA	AA
2.2: Study aggregate particle packing	AAA	A
2.3: Develop mix design methodology and criteria	AA	AAA
2.4: Investigate paste components and their roles	AAA	AAA
2.5: Recommend mix proportions for field study	AAA	AAA
3.1: Select construction time and location	AAA	-
3.2: Establish construction guidelines	AAA	AAA
3.3: Develop field data collection methods	AAA	AA
3.4: Perform field tests	AAA	AA
3.5: Analyze field data	AAA	AA
3.6: Prepare final report	AAA	AAA
Phase 4: Pavement performance monitoring	AAA	AA

Notes: AAA = heavily involved, AA = moderately involved, and A = involved.

DELIVERABLE PRODUCTS

Phase 1

- Interim research report at the conclusion of Phase 1: Feasibility Study with recommendations on the next phases of the research

Phases 2–4

- Demonstration projects, developed in collaboration with the TAC, for the implementation of pavement system design and construction using slip form SCC
- In consultation with construction equipment manufacturers, an assessment of the need to modify existing paving equipment to fit the new paving technology
- Recommendations concerning specifications for design and construction of slip form SCC
- Final research report
- Long-term properties, especially durability, of the new slip form SCC demonstration projects will be documented at 1, 3, 5, and 10 years, and performance reports will be furnished which will supplement the final research report.

PROJECT DURATION AND BUDGET

Project Schedule and Budget

Phase	Schedule	Budget
Phase 1: Feasibility Study	12 months	$175,000
Phase 2: Lab Study	12 months	$200,000
Phase 3: Field Investigation/Report	12 months	$175,000
Phase 4: Performance Monitoring	10 years	$ 40,000
		$590,000

Proposed Project Funding

A partnership for funding this research is proposed between state DOTs, industry, and the FHWA.

Phase	Budget	Sponsorship Goal Phase 1		
Phase 1: Feasibility Study*	$175,000	DOTs:	5 @ $5,000 =	$ 25,000
		Industry:	5 @ $10,000 =	$ 50,000
		FHWA:		$100,000
		Total Phase 1:		$175,000

*The TAC will decide at the conclusion of Phase 1 if the project will proceed to the next phases.

Phase	Budget	Sponsorship Goal Phases 2-4		
Phase 2: Lab Study	$200,000	DOTs:	10 @ $10,000 =	$100,000
Phase 3: Field Investigation	$175,000	Industry:	10 @ $10,000 =	$100,000
Phase 4: Performance Monitoring	$ 40,000	Industry:	6 @ $25,000 =	$150,000
	$415,000	PCC Center**:		$ 65,000
		Total Phases 2–4:		$415,000

**The PCC Center will provide up to $65,000 from other sources as necessary to complete the funding for this project.

Summary of Requirements for Project Sponsors

- Financial support
- Technical advisory committee participation

PROJECT ADMINISTRATION

The Iowa Department of Transportation, through the PCC Center at Iowa State University, will serve as the lead state and handle administrative duties for the project. Each participating entity may provide two individuals to serve on a technical advisory committee that will provide direction to the project. The TAC will organize the specifics of the cooperative work tasks and oversee the accomplishment of these tasks. The PCC Center, under the direction of the TAC, will provide administrative management and be the lead research institution on the project.

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