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INTRODUCTION

This paper presents a rational approach used for the evaluation of in-place concrete pavement with flexural strength requirements. There are a number of established procedures for evaluating hardened concrete with compressive strength requirements, where quality assurance testing of specimen cast from plastic concrete indicates a potential concern. However, there is only limited data and guidance available for the evaluation of hardened concrete with flexural strength requirements, where testing of beams cast from plastic concrete indicate a potential concerns.

During the construction of a concrete paving project at McCarran International Airport in Las Vegas, Nevada data was developed from the testing of over 450 specimens of concrete beams, cylinders, and cores representing samples from nearly 170 locations. Flexural, compressive, and splitting tensile strength testing was performed on these samples obtained from locations where comparison between the different types of strength tests was possible.

Relationships between this data were evaluated and a rational approach to the evaluation of in-place concrete for compliance with flexural strength requirements was developed. This approach, that begins with trial batch data and includes cast and cored specimen, could be applied to other concrete paving projects with similar concerns.

PROJECT

The project consisted of replacement of concrete pavement panels in the apron, tarmac, and taxiway areas of McCarran International Airport. The work included in this study included 432 mm thick concrete pavement and was performed between October, 1999 and May, 2000.

The project owner is the Clark County Department of Aviation, who retained the Bechtel Corporation as their program manager for the design and construction of this project. Kleinfelder, Inc. was contracted by the Clark County Department of Aviation to perform quality assurance and product acceptance testing. Stantec, Inc. performed the trial batch testing for the contractor, MMC, Inc.

These specifications required testing to be performed in accordance with specific standard ASTM procedures. These procedures were strictly followed in the field and laboratory, including on-site, temperature-controlled initial (field) curing structures. Equipment was precisely calibrated, including specialized calibration of the third point loading apparatus by Construction Technologies Laboratories to assure the uniform transfer of loads to the flexural beam specimen.

SCOPE OF STUDY

During this project, data was developed that included strengths from laboratory batched trial mixes, field cast specimen from production materials, and concrete cores obtained from the in-place concrete pavement. Trial batch data included flexural strengths of cast 152 mm by 152 mm beams with a third point loading total span of 457 mm and compressive strengths of cast 152 mm diameter by 305 mm" high cylinders. Both beams and cylinders were tested at ages of 1, 3, 7, 14, 21, 28, 35, and 90 days.

Field cast flexural strength concrete beams were also 152 mm by 152 mm in size with third point loading total spans of 457 mm. Field cast beams were tested at an age of 28 days. 152 mm diameter by 305 mm high cylindrical specimen were also cast in the field from production concrete and tested for compressive and spilt tensile strength.

Drilled cores were 100 mm diameter and approximately 432 mm length. Cores were trimmed to the required testing length. Typically two samples were sawn and tested for each core. Both compressive strength and splitting tensile strengths were performed on cores, whose ages ranged from 43 to 82 days.

Flexural strength tests were performed in accordance with ASTM C 78. Compressive strength tests of cast cylinders were performed in accordance with ASTM C 39. Splitting tensile strength tests were performed in accordance with ASTM C 496. Cores were obtained and tested in accordance with ASTM C 42.

Filed samples of plastic, production concrete were obtained in accordance with ASTM C 31. The location of field samples of plastic concrete and cores were determined by a random sampling procedure in accordance with ASTM D 3665. The random locations of plastic concrete and core samples were determined independently. Therefore, although the plastic concrete and core samples were from the same sublot, they were not necessarily from the same batch (truckload) or location. This prevented the development of relationships between the cores and the cast beam test results. There were 3 to 4 sublots for each day of production and typically less than 200 cubic yards of concrete per sublot. Batches were typically 10 cubic yards in size.

The trial batches tested 3 beams and 3 cylinders for each age. The field data produced strengths for cast beam samples at 87 sublot locations. Cores were also obtained at 33 sublot locations.

Based upon the trial batch data, relationships were developed between flexural strength and compressive strength. Field data of beam and cylinder specimens cast from the same production sample in the field were used to develop relationships between flexural, compressive, and splitting tensile strength.

These relationships were compared to published typical relationships presented in referenced texts and the FAA Engineering Brief # 34 and Advisory Circular No. 150/5320-6D. Using statistical procedures, a conclusion was developed regarding the confidence of using this type of rational to evaluate in-place concrete pavement specified using flexural strength.

DATA

Flexural, compressive, and splitting tensile strength tests were performed on this project and are the topic for this paper. These test results are presented in the figures that follow. Figs. 1 and 2 present the data plotted with respect to the relationships of the data to other properties. Fig. 2 also presents this data in an analysis form, where relationships are used to convert splitting tensile strength to flexural strength. Figs. 3, 4, and 5 present the data based upon analysis of the relationships between the different types of strength tests.

Using the trial batch field data for cast specimens, the relationship shown in Fig. 1 was established between flexural and compressive strengths. Using the strength data of beams and cylinders cast from plastic concrete used in the production of the in-place concrete pavement, the relationship between flexural and splitting tensile strengths is shown in Fig. 2.

DATA ANALYSIS

Data was analyzed using the previously described above relationships; the relationship ranges published in the text, *Composition and Properties of Concrete*, Second Edition, Troxell, Davis and Kelly, published by McGraw-Hill, Inc., 1968; and also relationships presented in FAA Advisory Circular 150/5320-6D. Figs. 2 through 5 present the compressive and splitting cylinder conversions to flexural strength using the referenced text and FAA Advisory Circular relationships. These relationships are as follows:

Composition and Properties of Concrete--Flexural Strength equals a constant times the square root of the compressive strength, where the constant ranges from 8 to 10. (Results in psi, convert to MPa by multiplying times 0.006895). Flexural Strength equals the splitting tensile strength divided by a constant, where the constant ranges from 0.5 to 0.75. (Results in psi, convert to MPa by multiplying times 0.006895)

FAA Advisory Circular 150/5320-6D and Engineering Brief # 34--Flexural Strength equals 9.0 times the square root of the compressive strength. . (Results in psi, convert to MPa by multiplying times 0.006895). Flexural Strength equals 1.02 times the splitting tensile strength (psi) + 117 psi. (Results in psi, convert to MPa by multiplying times 0.006895)

Fig. 2 shows the conversion of splitting tensile strength of cast cylindrical concrete specimen using the relationships presented in the different sources and developed from the field data. Fig. 3 depicts the conversion of the core data from compressive to flexural strength using the relationships presented in the different sources and developed during the trial batch.

The correlation coefficient for each of these relationships was used to determine the degree to which a valid statistical relationship exists between the two ranges of data being compared. Correlation coefficients of near 1.0 indicate a definite statistical relationship exists between the to properties being charted. The further away from 1.0, the less the statistical relationship that exists.

The correlation coefficient of 0.99 for the trial batch relationship of compressive to flexural strength indicates an excellent statistical relationship exists between these two strength properties. This was not the case for the specimen cast from production materials in the field.

Likewise, the correlation coefficient for the relationship of splitting tensile and flexural strength for field cast specimen was 0.0002, indicating a statistical relationship between these two properties is nearly nonexistent. Splitting tensile strength testing was not performed during the trial batch.

The absence of a discernible statistical relationship for the field cast specimen is likely the result of data that is too tightly grouped to dampen the effects of testing variables. Field operations targeted a specified strength range, where as trial batch data was available over a broad range of strengths. For example, the trial batch data ranged from 2.6 to 5.8 MPa (3.2 MPa) for flexural strength and 14.1 MPa to 51.4 MPa (37.3 MPa) for compressive strength. The field data ranged only from 4.6 to 5.1 MPa (0.5 MPa) for flexural strength and 43.2 to 47.4 MPa (4.2 MPa) for compressive strength.

The total ranges of strength data for the field cast specimen were within the range of reproducibility of the respective tests. ASTM C 78 states: "...results of two properly conducted tests by the same operator on beams made from the same batch sample should not differ from each other by more than 16%." The entire range of flexural strength values for the field data in Fig. 1 is about 11%.

Fig. 4 shows the relationship between flexural strengths calculated from compressive strengths of cores and flexural strengths calculated from splitting tensile strengths of cores obtained at the same location. The FAA Advisory Circular formulas were used for both of the compressive and splitting tensile strength calculations. The trial batch formula was used for the compressive strength calculation. The compressive strength conversion uses the two different formulas applied to the compressive strength of the same core. The splitting tensile strength conversion uses a formula applied to a splitting tensile strength of a different core from the same sample.

The calculated flexural strengths by the two different methods track each other well, high strengths match high strengths, low strengths match low strengths. However, the flexural strengths calculated using the splitting tensile strengths are always higher that those calculated using the compressive strength. This indicates that the two properties are equal in their statistical relationship regardless of the FAA Advisory Circular formula used.

Fig. 5 contains data from 6 samples from which cylinder and beam specimen were cast and flexural, compressive, and splitting tensile strength tests were performed. Flexural strengths were calculated using a variety of methods and are compared on the figure with the flexural strengths obtained directly from the beams.

The calculated methods again track very well with each other, but not necessarily with the beam strengths, although the range from highest to lowest value was very small. Contrary to the drilled core specimens, for these cast specimens, the splitting tensile strength was always the lowest for each sample. The flexural strength by any of the calculated methods did not very from the flexural strength of the beams by more than 18% for any sample. Considering the uncertainty created by the testing variability of the multiple types of tests, the correlation of the various conversion formulas is remarkable.

CONCLUSIONS

Based upon the data from this study and the comparison of that data to published relationships, a statistic relationship exists between flexural strength and both compressive and splitting tensile strength. Relationships are valid for both compressive and splitting tensile strengths from both drilled cores and cast cylinders.

Statistically valid relationships can be developed during the trial batch testing of a concrete mix.

The use of typical formulas presented in the FAA Advisory Circular can be used to develop a reasonable approximation of flexural strength using either compressive or splitting tensile strength conversions. Both the trial batch and FAA Advisory Circular conversion methods fall within published ranges for the data from this study.

Because the strength properties of concrete can vary significantly with differing component materials, the approach of developing relationships during trial batching is important to provide an added degree of confidence in the conversion formulas being used. Using a multi-faceted approach of trial batch and production data, cast and cored specimen, and flexural, compressive, and splitting tensile tests allows the evaluator to develop a feeling of the range of concrete strength properties of the in-place material. This will provide direction for further investigation of potential problem areas and development of solutions in which owner, designer, construction contract administrator, quality assurance and control personnel, and construction contracting parties to the project can be sufficiently confident.

As a corollary to this approach, compressive and/or splitting tensile strength testing on a regular basis during production from the same sample as the flexural strength testing can develop substantial quantities of data to build the relationships among the strength properties. This data and the relationships developed from it can be used to identify sampling or testing problems with cast specimen and to develop increased confidence in evaluation of in-place concrete using compressive or splitting tensile strengths, should it become necessary.

References

(1) *Composition and Properties of Concrete*, Second Edition, Troxell, Davis, and Kelly, McGraw-Hill, Inc., 1968

(2) FAA Advisory Circular 150/5320-6D

(3) FAA Engineering Brief # 34

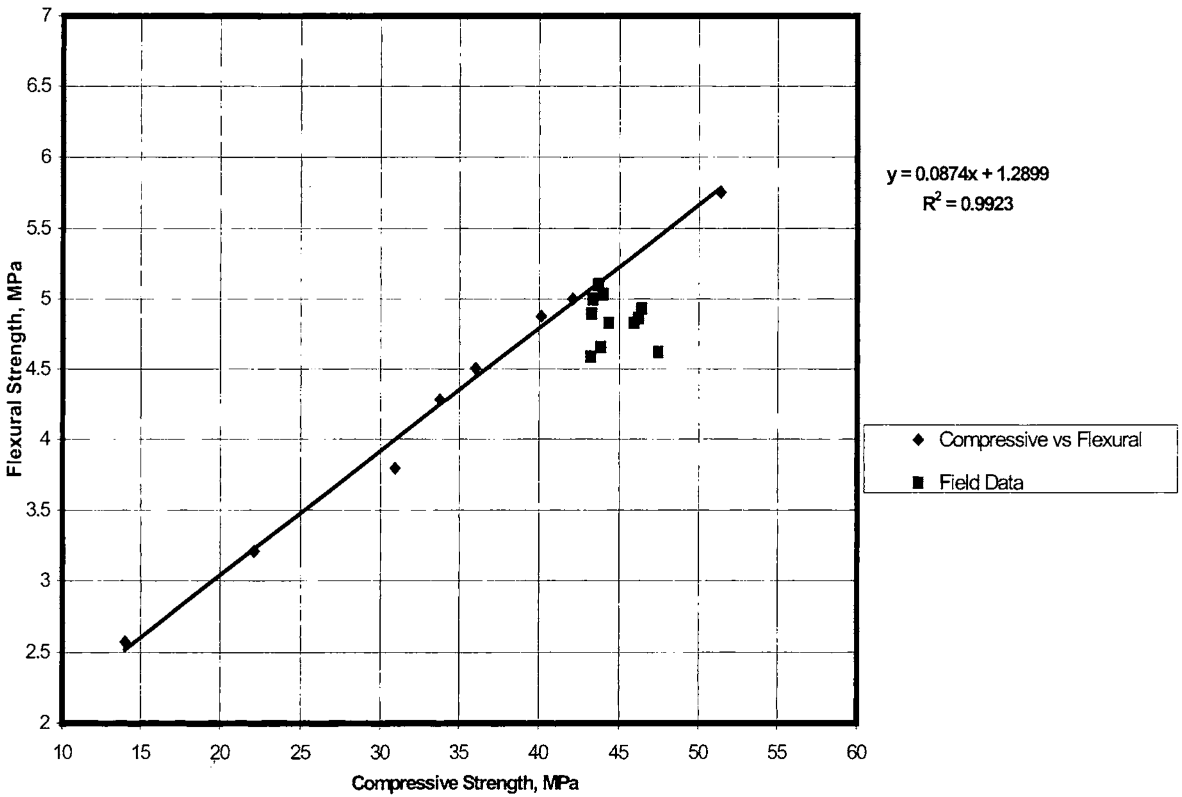

Fig. 1 Cast Cylinder Specimen, Trial Batch and Field Data Compressive to Flexural Strength Relationship

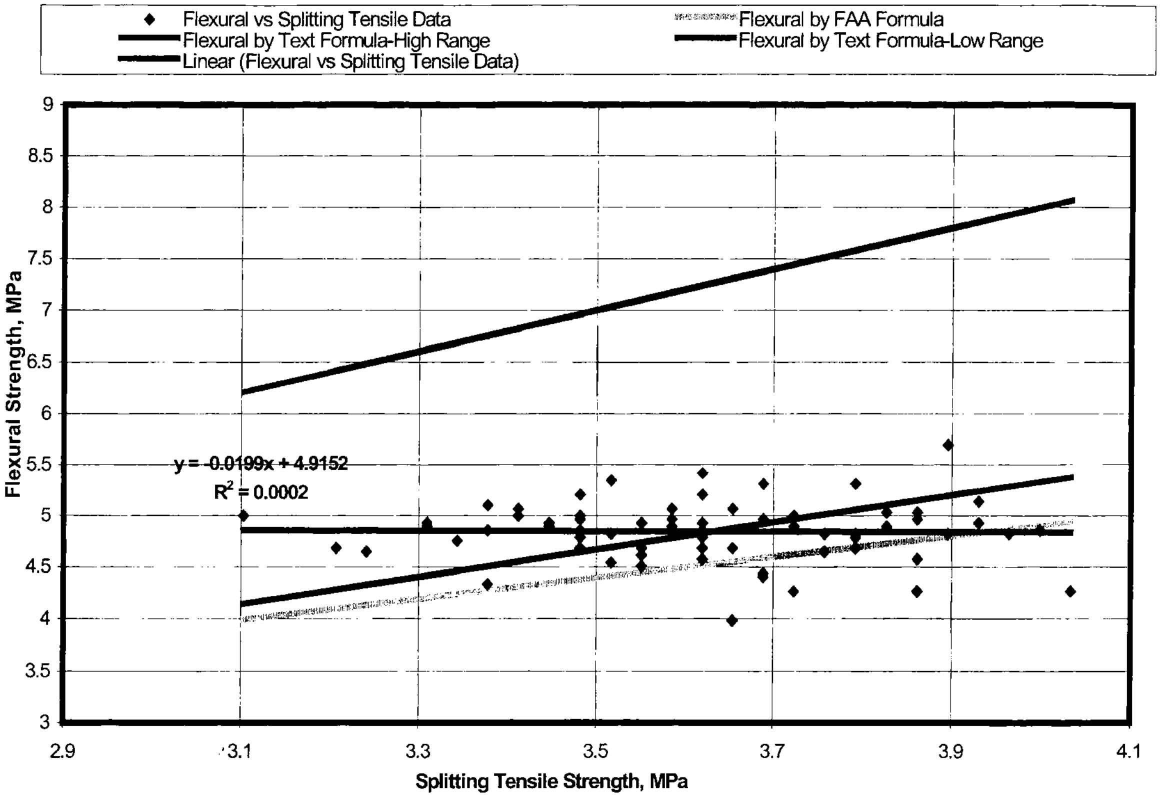

Fig. 2 Cast Specimen of Field Sampled Concrete Flexural to Splitting Tensile Strength Relationship

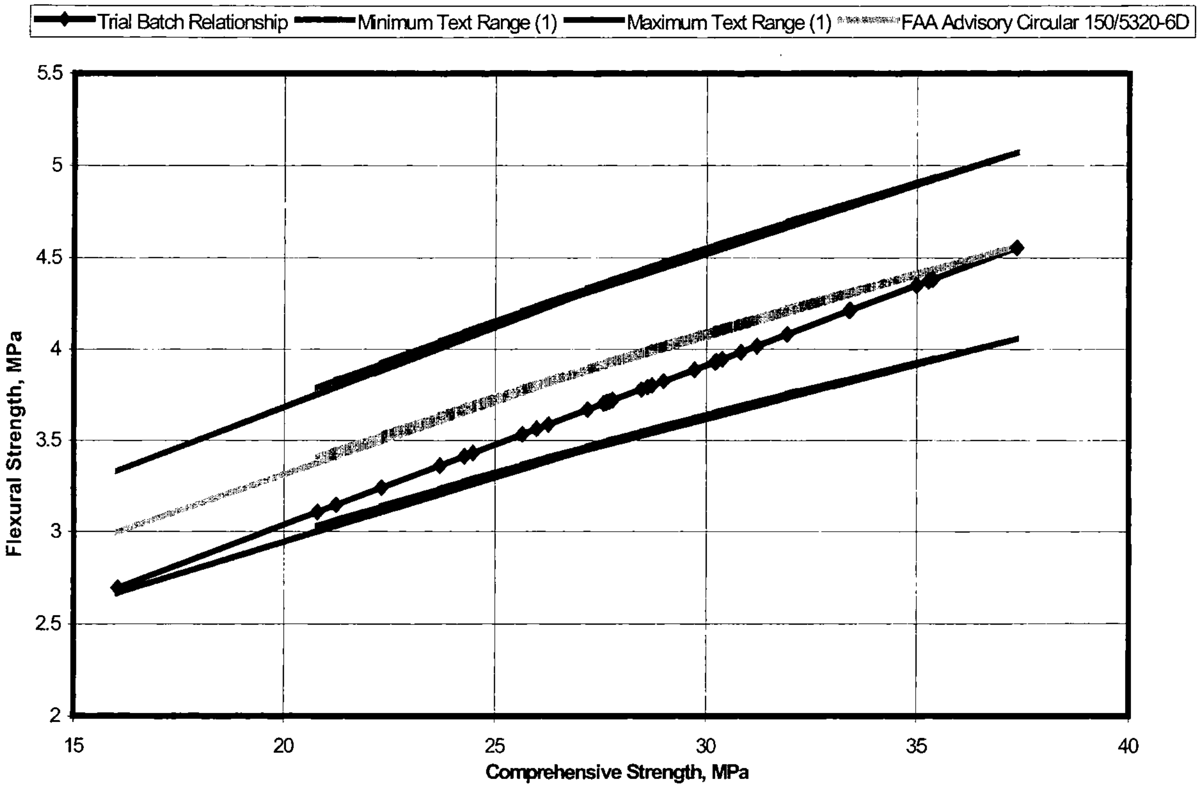

Fig. 3 Field Compressive Strength of Cores Data Compressive Strength Converted to Flexural Strength Using Various Relationships

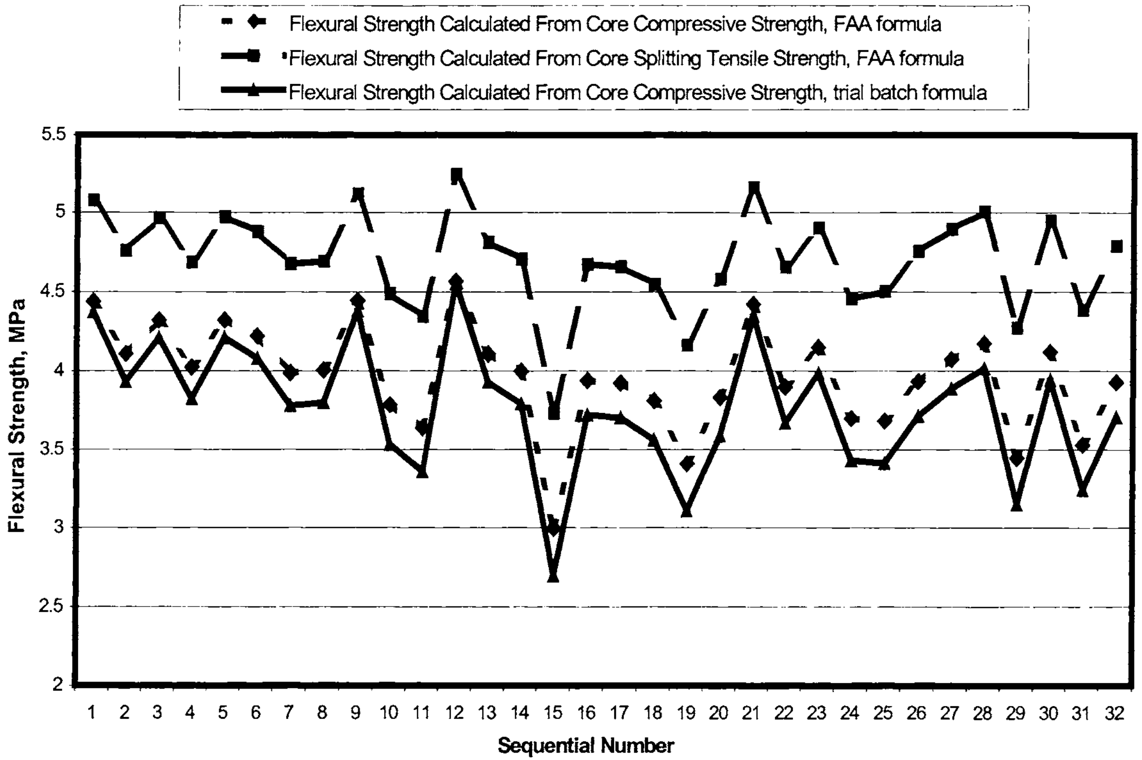

Fig. 4 Field Core Data
Flexural Strengths Calculated From Compressive and Splitting Tensile Strengths Using the FAA Advisory Circular 150/5320-6D and Trial Batch Formulas