Synthesis Study on Load Capacity of Concrete Slab Bridges without Plans

Richard Miller

Bahram Shahrooz

Paul Gearhart

Ohio's Research Initiative for Locals

ORIL

University of Cincinnati

Problem Statement

- It is estimated there are over 1200 concrete slab bridges with unknown properties in Ohio.
- Previously, visual inspection was adequate to assess these bridges.
- FHWA now requires numerical rating.
- In some counties, loads have increased due to oil and gas exploration.

PARAMETERS NEEDED TO RATE A SLAB BRIDGE

- Geometry
  - Span, slab thickness, condition of support
- Concrete strength, f_c'
- Reinforcing bar
  - Yield strength, f_y
  - Effective Depth, d
  - Area of Bar A_s (bar diameter and spacing)

OBJECTIVE

Provide ODOT and County Engineers with a suite of possible tools to determine the properties of concrete slab bridges.

PROPOSED TEST METHODOLOGY

- Historical record
- Standard drawings
- Non-destructive or minimally invasive field/lab measurements
  - A literature search and a survey were used to find the probable accuracy of various methods.

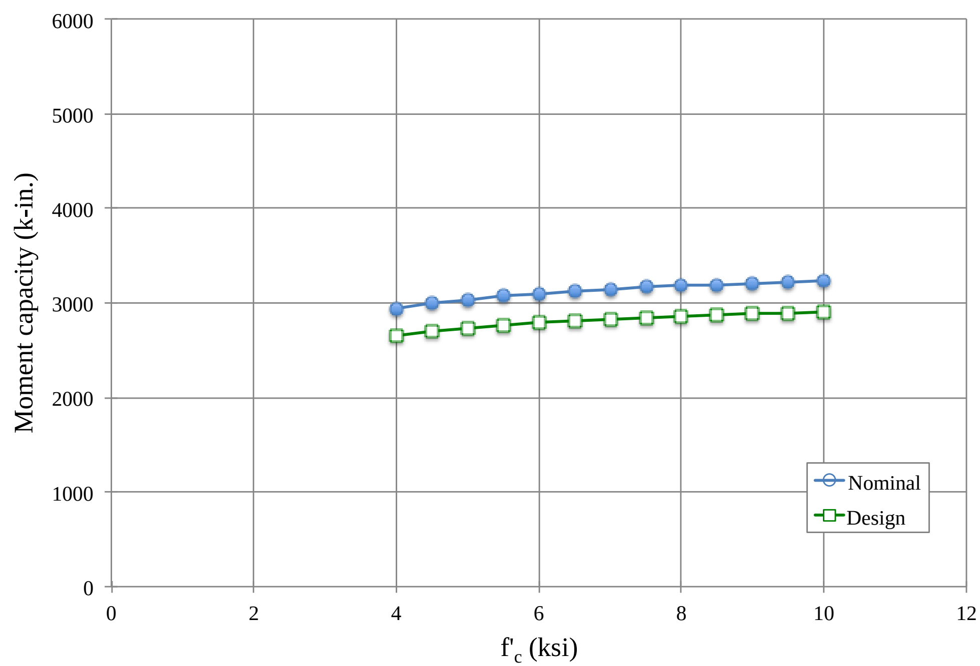
PROPOSED TEST METHODOLOGY - GEOMETRY

- Determine bridge geometry.
  - This is done through simple measurement of the slab thickness and span length(s).
- Condition of support is more difficult to determine.
  - Literature suggests it is somewhere between fixed and pinned. Conservative to assume a pin unless the abutment is integral.

CONCRETE STRENGTH

Oddly, concrete strength is not a critical parameter since the SLAB is a flexural element. The graph shows the influence of concrete strength on moment capacity of a rectangular beam.

Note that doubling the concrete strength only increases moment capacity by about 10%!!



PROPOSED TEST METHODOLOGY – CONCRETE STRENGTH

- Coring is the most accurate method of strength determination but it expensive and it does some damage to the bridge.
  - It may be possible to core in a shoulder area.
- Usually, 3 cores are needed.

PROPOSED TEST METHODOLOGY – CONCRETE STRENGTH

- Historical data/specifications may provide an estimate of specified strength.
  - If the date of construction can be estimated, many slab bridges used standard specifications. It may be possible to estimate the design strength from these records.
  - Sometimes material strength records are kept separately and data may be available.

PROPOSED TEST METHODOLOGY – CONCRETE STRENGTH

– NDT techniques like rebound hammer or Windsor probe may provide accurate enough results for rating as concrete strength is not an important parameter.

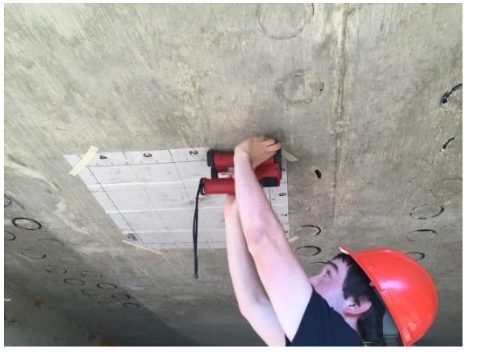
- Data suggests NDT techniques without calibration by coring are +/- 1500 psi on strength.
- Rebound hammers are less accurate near edges or on thin members.

PROPOSED TEST METHODOLOGY – CONCRETE STRENGTH

- Rating is usually done using design strength. NDT methods measure actual strength which is usually greater than design strength; especially in older bridges.
- Large errors in concrete strength have little effect on rating flexural members.
- NDT is likely accurate enough for slabs but not for compression members.

REINFORCING BAR - MAGNETOMETER

- Can be used to find bar size, spacing and cover.
- Relatively cheap (about $2500).
  - Could be rented or shared.
  - ODOT has one!



- Very easy to use!
  - Better models download results to a computer

PROPOSED TEST METHODOLOGY COVER

- Cover is needed to determine effective depth, d.
- Effective depth is important as moment capacity, M_n, is directly proportional to d.
- Magnetometer accuracy:
  - Cover of 1.75 inches or less, error < 10%
  - Covers exceeding 1.75 inches: error increases as cover increases. Errors may be as high as 20%.
  - For many cases, the error is about +/- 3/8 inch.
  - Magnetometer generally cannot detect covers exceeding 3 inches but ground penetrating radar can be used.

OHIO'S RESEARCH INITIATIVE for LOCALS ORIL

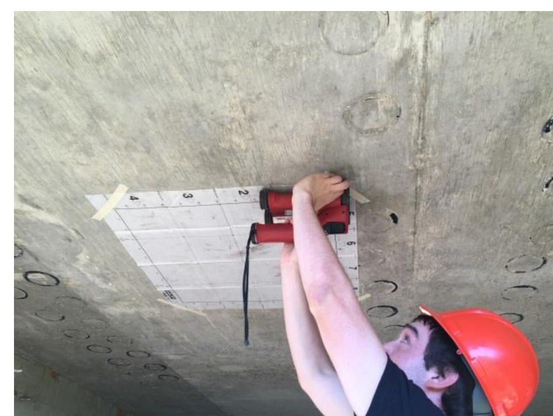
UNIVERSITY OF Cincinnati

PROPOSED TEST METHODOLOGY STEEL AREA

- Area of steel is an important parameter.
- Over typical reinforcing ratios, the moment capacity, M_n, is almost directly proportional to steel area.
- Steel area is found from two parameters:
  - Bar spacing
  - Bar size

PROPOSED TEST METHODOLOGY BAR SPACING

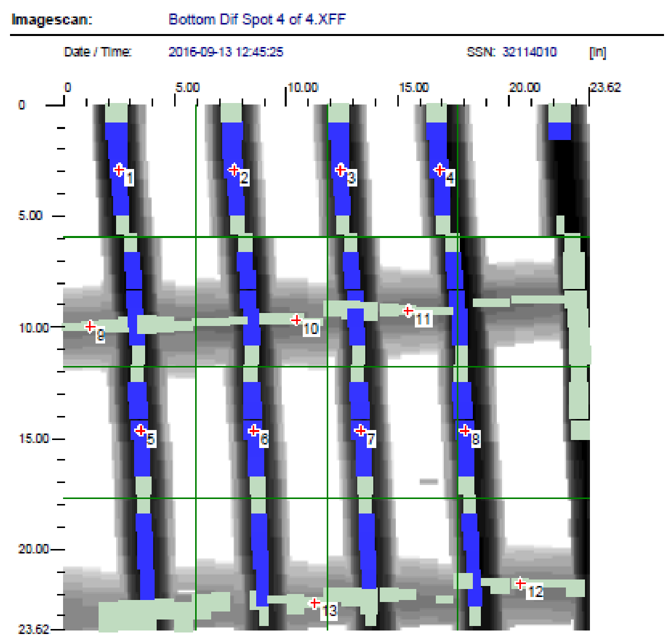
- Magnetometer can find bar spacing for cover < 3 in.
- Accuracy is about +/- 3/8 in, but a large number of readings allow for reasonable determination of bar spacing.
- Magnetometer can also locate bar ends.
- GPR needed for large covers.



Ohio's Research Initiative for Locals ORIL

University of Cincinnati

PROPOSED TEST METHODOLOGY BAR SPACING



Actual magnetometer scan.

PROPOSED TEST METHODOLOGY BAR SPACING

- It is sometimes possible to verify bar spacing by another means.
- Often, older bridges have deteriorated areas with exposed bar.
- Slab bridges were often built using standard details. Magnetometer results can be checked against standard detail of the era to see if they match.

PROPOSED TEST METHODOLOGY BAR SIZE

- Magnetometer can find bar size for cases of cover < 3 inches.
- The accuracy is plus or minus one bar size.
- The accuracy deteriorates as the cover gets larger.
- Using a large number of readings may improve accuracy by taking an average bar size.

PROPOSED TEST METHODOLOGY BAR SIZE

– The engineer must use some judgement on the bar size results.

– If needed bar size can be verified by:

  - Finding a deteriorated area
  - Taking a core

– The magnetometer is then used to verify spacing, bar ends and if all the bars are the same diameter.

PROPOSED TEST METHODOLOGY

- Problems with magnetometer
  - Not usable for very large covers.
  - Skewed bars can cause a problem unless the scan is done along the skew.
  - Very close spacing affects the reading as adjacent bars affect the magnetic field.
  - Lap splices are seen as bigger bars.
  - Voids/delams in the concrete affect readings.

YIELD STRENGTH

- Yield strength of reinforcing bars is a critical parameter.
- Moment capacity is directly proportional to yield strength.
- No easy method to measure this *in situ*.

OHIO'S RESEARCH ORIL INITIATIVE for LOCALS

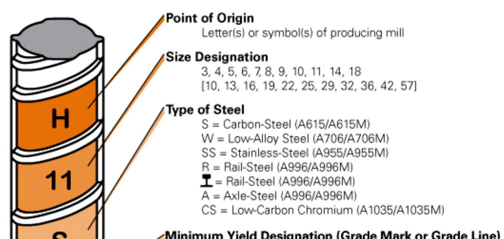
UNIVERSITY OF Cincinnati

YIELD STRENGTH – MEASUREMENT

- Historical Records
  - CRSI has records of historical bar. During certain eras, there was a maximum bar strength.
    - Prior to 1959
      - Structural (f_y=33ksi)
      - Intermediate (f_y=40ksi)
      - Hard (f_y=50ksi)
    - Grade 60 did not appear until 1959.
    - Most newer bridges will use Grade 60 reinforcing bars.

YIELD STRENGTH MEASUREMENT

- Historical Record
  - CRSI has mill mark data.
  - If a mill mark can be found (perhaps in a deteriorated area), the bar can be identified.



Inch-Pound Markings		Metric Markings	
60	Grade 60*	4	Grade 420*
75	Grade 75**	5	Grade 520**
80	Grade 80***	6	Grade 550***
100	Grade 100***	6	Grade 690***
120	Grade 120****	8	Grade 830****
None	Grade 40 or 50	None	Grade 280 or 350

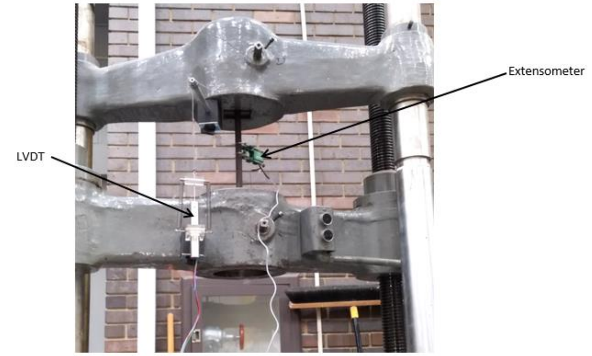
*Or 1 Grade Line / **Or 2 Grade Lines / ***Or 3 Grade Lines / ****Or 4 Grade Lines

For stainless-steel (ASTM A955/A955M) reinforcing bars:
"•" for Grade 60 [420], "••" for Grade 75 [520]

Figure courtesy of CRSI.

YIELD STRENGTH MEASUREMENT

- Tensile testing of a reinforcing bar removed from a structure AASHTO T68.
  - It is possible that a bar sample could be removed from a deteriorated area.
  - This test needs an approximately 3 foot long sample, which is probably impractical.



YIELD STRENGTH MEASUREMENT

- Tensile testing under AASHTO T244.
- This method uses a machined specimen.
- Standard size is 0.5 inch diameter with a 2 inch gauge length.
- Overall length is about 6 inches.
- Could be a bar removed from a deteriorated area.

YIELD STRENGTH MEASUREMENT

- Obtaining a 6 inch long bar might be impractical.
- Tensile testing under AASHTO T244 allows bars as small as 0.113 inch diameter with a 0.45 inch gauge length.
- One drawback to AASHTO T244 is machining costs.

YIELD STRENGTH MEASUREMENT

- Two possible alternate methods
  - Compression testing.
    - ASTM E 09 actually provides a method of using compression testing.
  - Hardness testing
    - Literature suggests that there is a relationship between hardness and strength.

YIELD STRENGTH MEASUREMENT COMPRESSION TESTING

Compression Testing

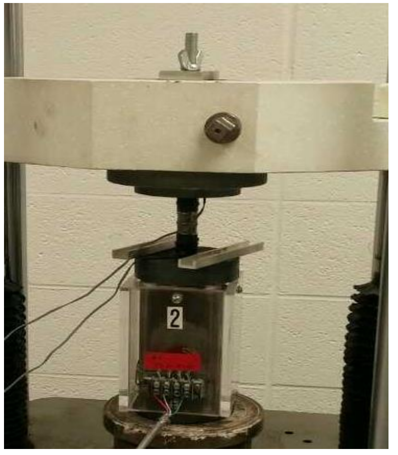
Structural steel sections can be tested in compression if kL/r $\leq$ 6.0.

This assure buckling is not a issue.

A 3 inch long specimen would have kL/r $\leq$ 6.0 for #4 bar size and larger. A 3 inch bar length can be obtained by cutting it from a deteriorated area or from a 3.5 or 4 inch core.

YIELD STRENGTH MEASUREMENT COMPRESSION TESTING

- The ends need to be machined flat and parallel (but this less machining than a T244 specimen).
- Hardened end plates are used.
- Guide pins center the specimen.

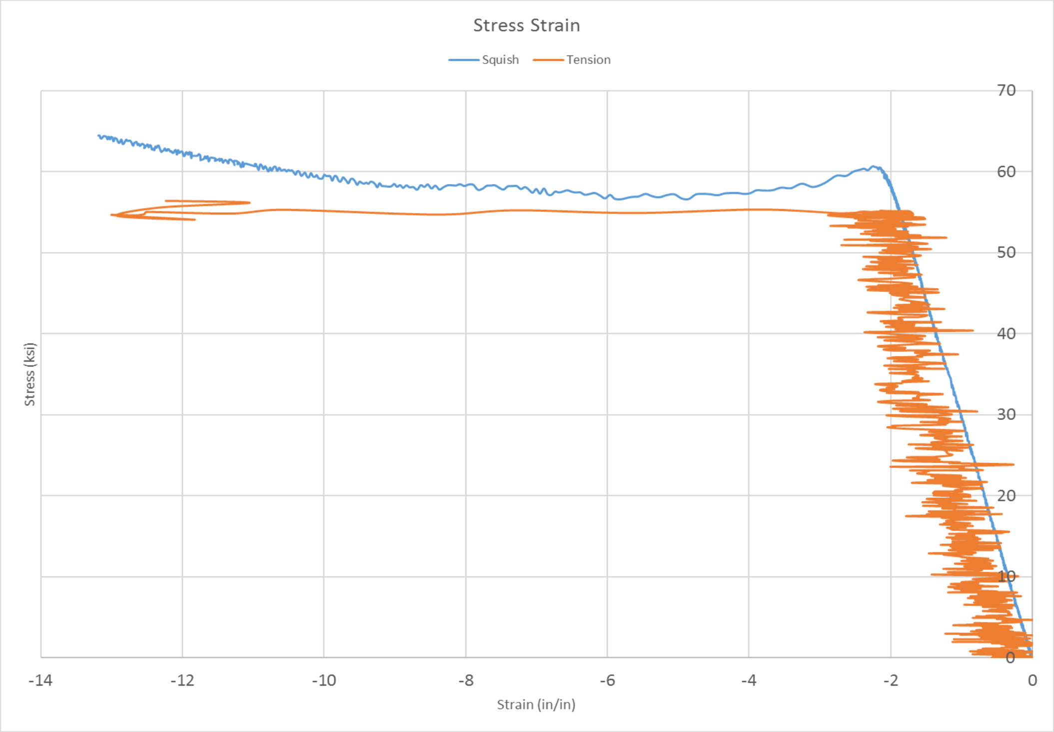


YIELD STRENGTH MEASUREMENT COMPRESSION TESTING

- Strain gauges were used to measure stress/strain curves.
- The sides of the bar had to be ground to allow the gauges to be attached.

UNIVERSITY OF Cincinnati

YIELD STRENGTH MEASUREMENT COMPRESSION TESTING



Comparison of a tensile test with a compression test

YIELD STRENGTH MEASUREMENT COMPRESSION TESTING

- There was some difference, usually about 5%-10% between the compression and tensile tests.
- However, this is accurate enough to determine the Grade of the bar, which is used for rating.

YIELD STRENGTH MEASUREMENT - HARDNESS

Literature suggests that there may be a relationship between strength and hardness.

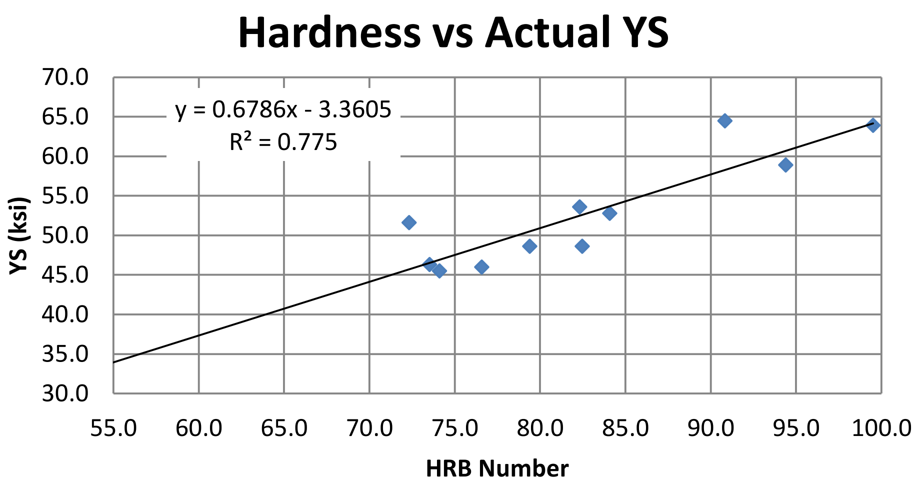
Nominal strength is used for rating. Thus the test has to only be accurate enough to identify grade.

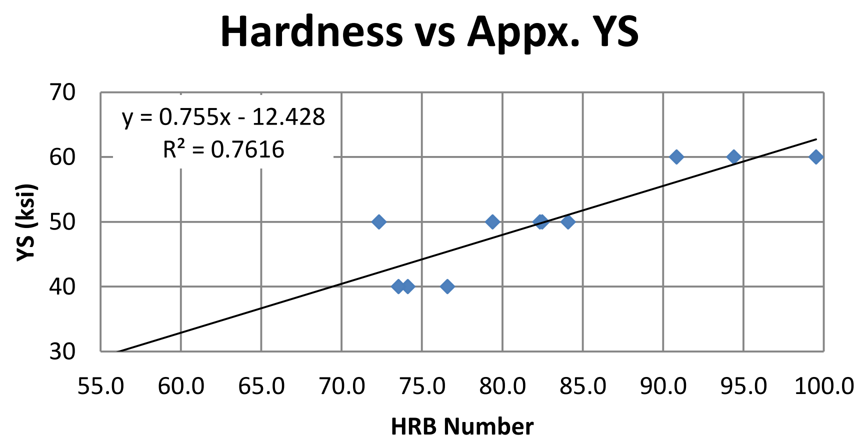
YIELD STRENGTH MEASUREMENT - HARDNESS

- The research team collected samples of old reinforcing bar.
- Bars were tested for yield and tensile strength.
- Rockwell “B” hardness was also tested.

YIELD STRENGTH MEASUREMENT - HARDNESS

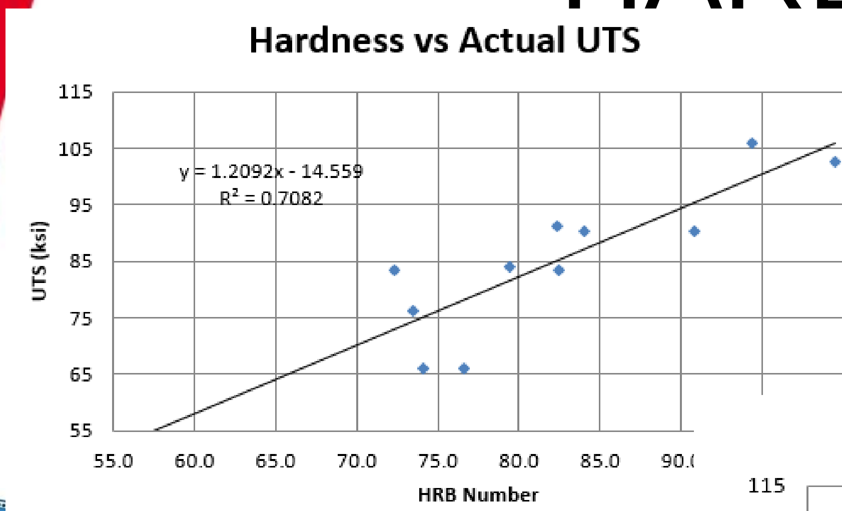
YS = Yield Strength

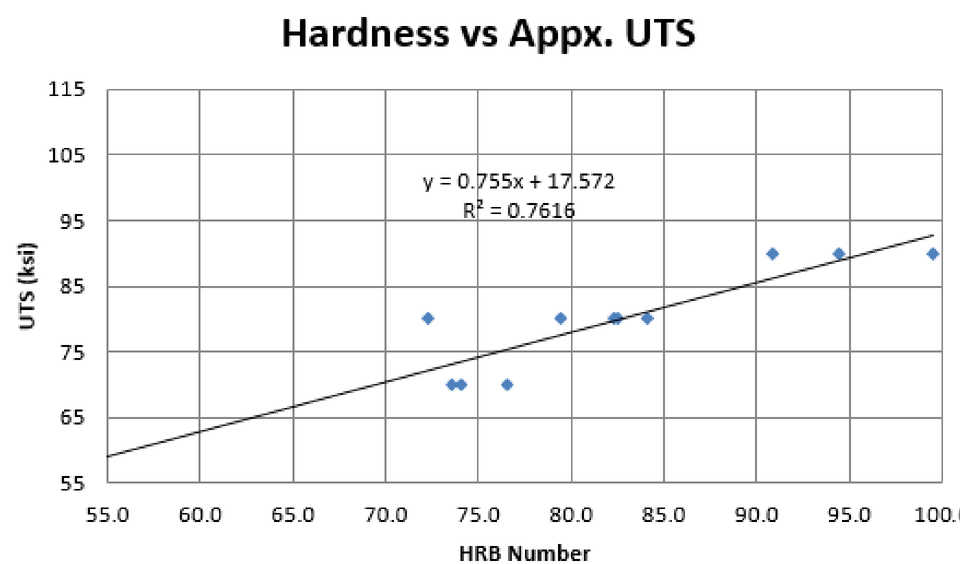




YIELD STRENGTH MEASUREMENT - HARDNESS

UTS = Ultimate Tensile Strength

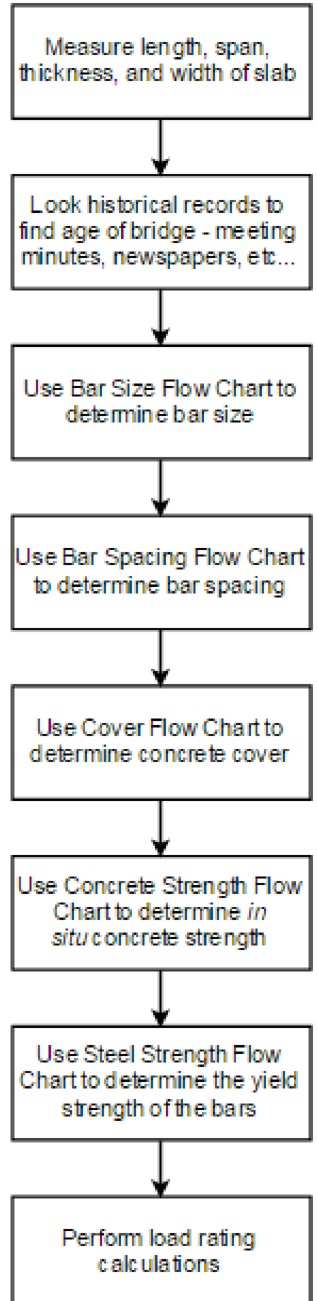


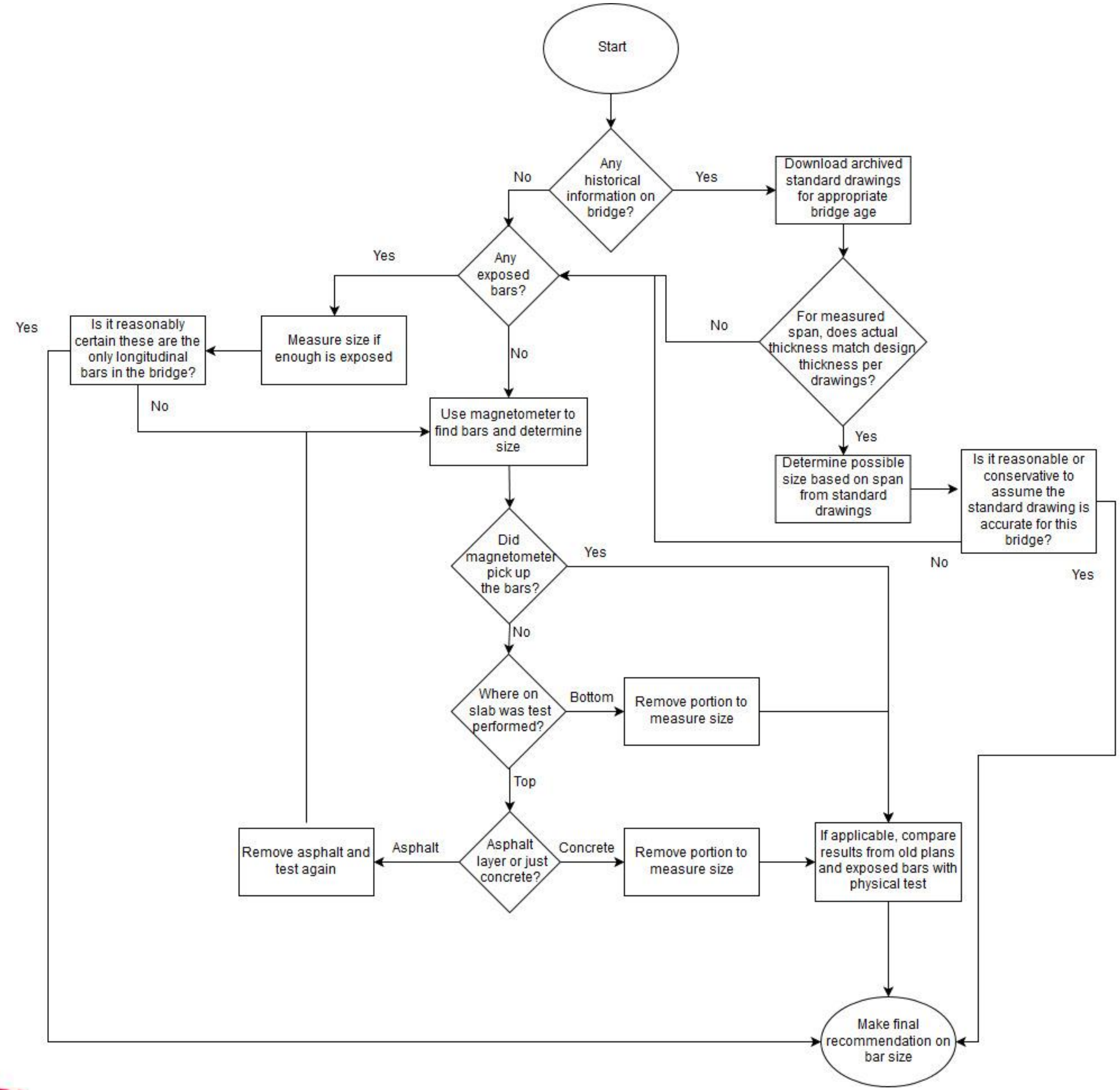


UNIVERSITY OF Cincinnati

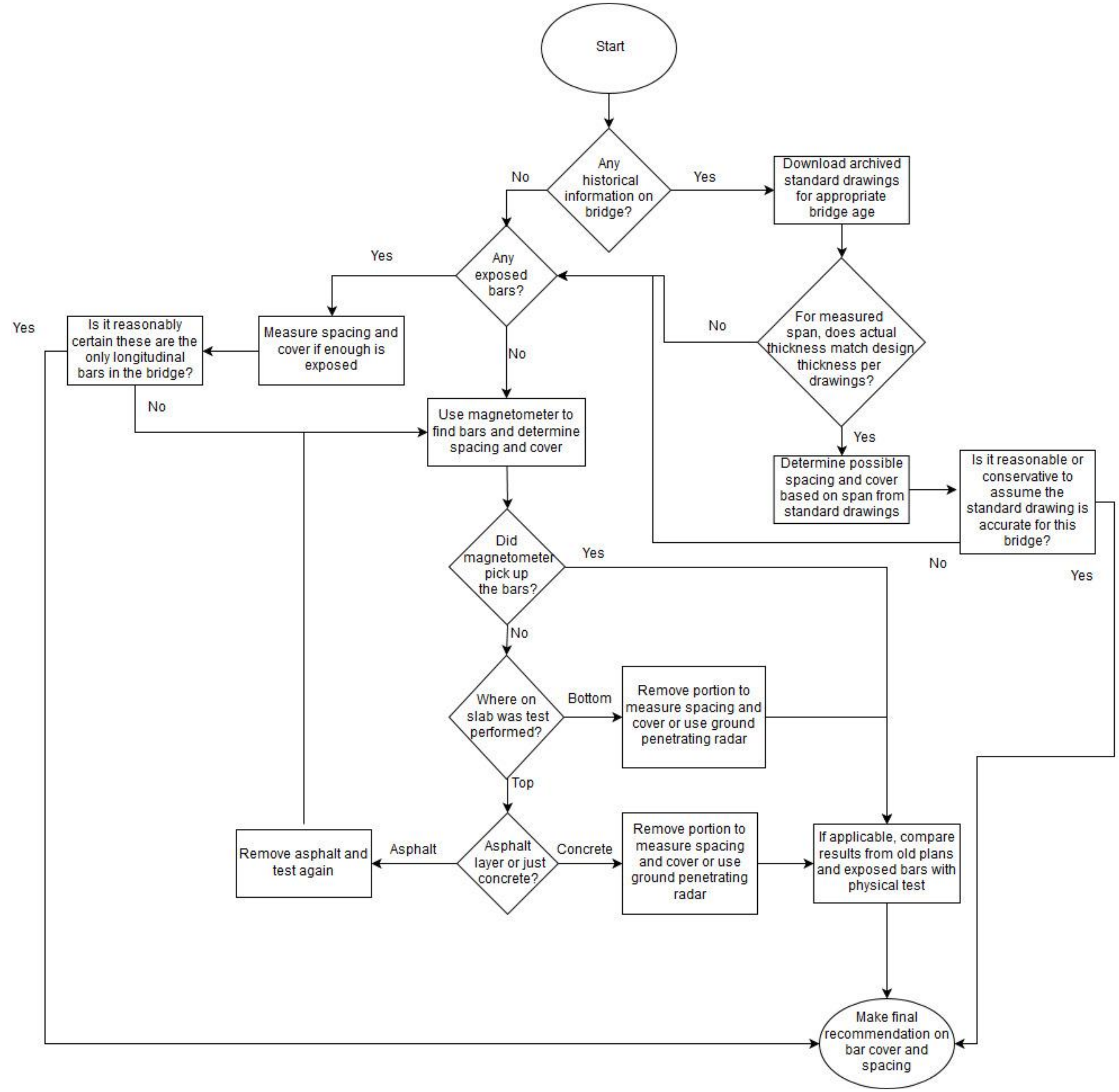
YIELD STRENGTH MEASUREMENT - HARDNESS

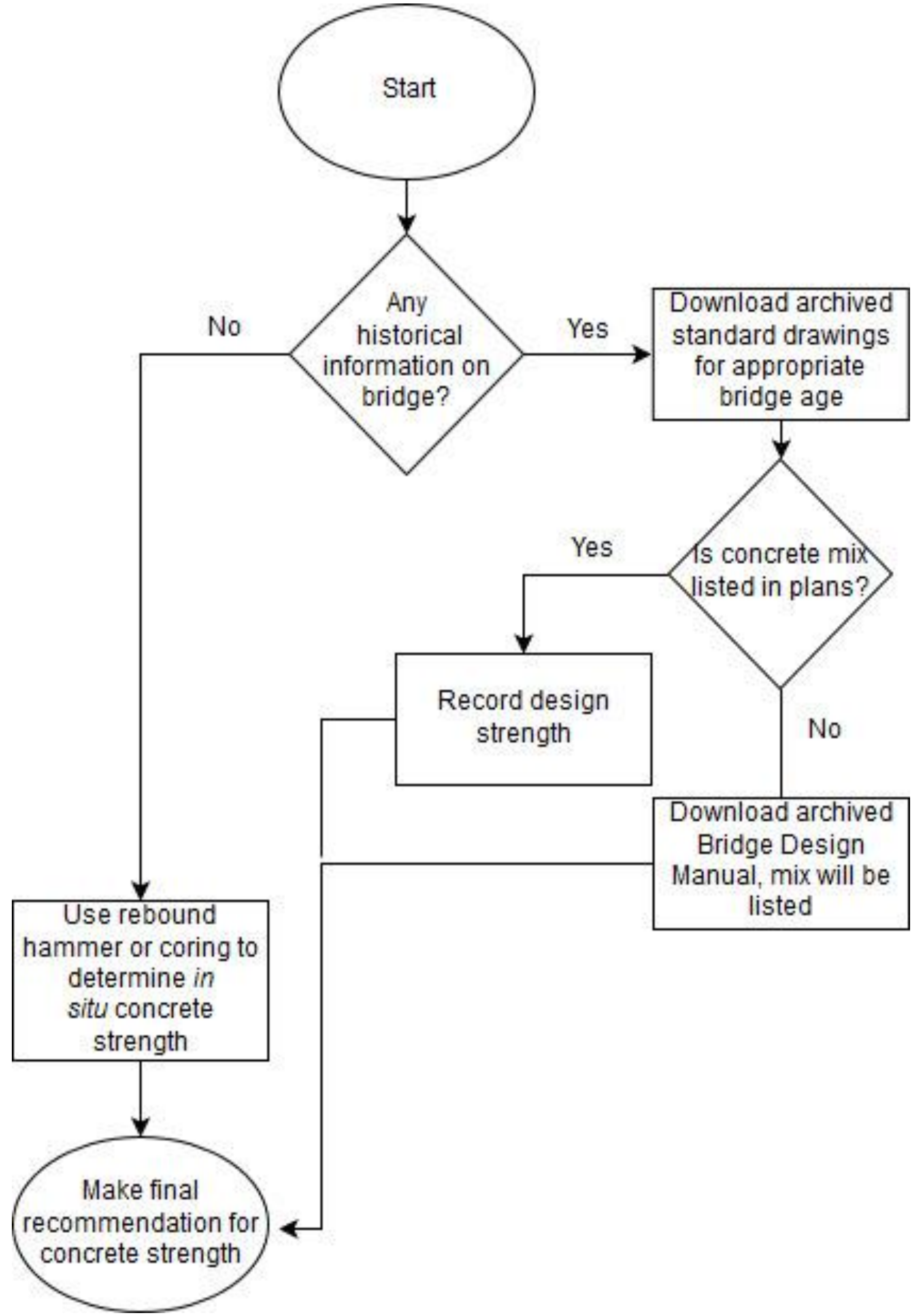
- There appears to be a reasonable enough relationship between hardness and strength to find Grade.
- Portable hardness testers are available for field use which could be used on an exposed bar.

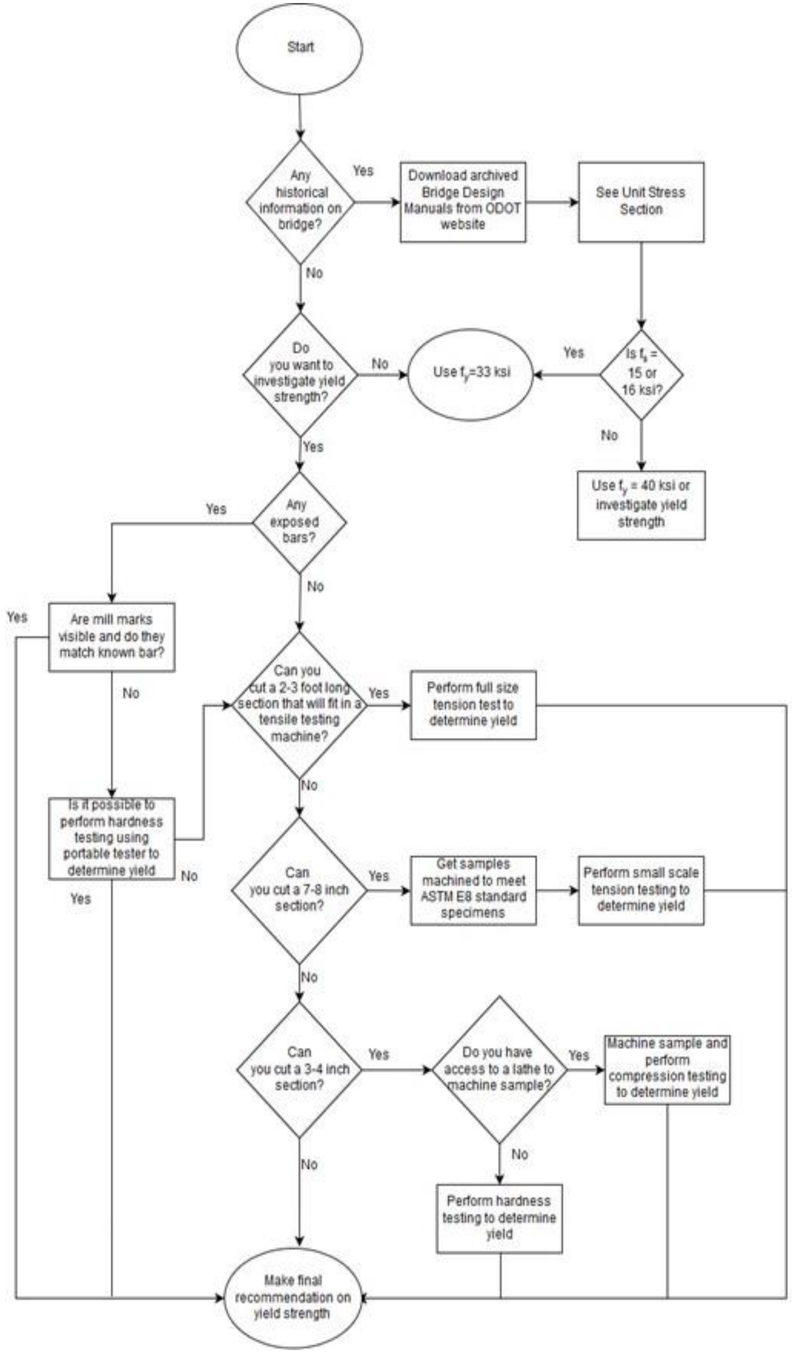

Measure length, span, thickness, and width of slab
Look historical records to find age of bridge - meeting minutes, newspapers, etc...
Use Bar Size Flow Chart to determine bar size
Use Bar Spacing Flow Chart to determine bar spacing
Use Cover Flow Chart to determine concrete cover
Use Concrete Strength Flow Chart to determine *in situ* concrete strength
Use Steel Strength Flow Chart to determine the yield strength of the bars
Perform load rating calculations



UNIVERSITY OF Cincinnati


Start
Any historical information on bridge?
No
Yes
Download archived standard drawings for appropriate bridge age
For measured span, does actual thickness match design thickness per drawings?
No
Yes
Determine possible spacing and cover based on span from standard drawings
Is it reasonable or conservative to assume the standard drawing is accurate for this bridge?
No
Yes
Any exposed bars?
Yes
No
Measure spacing and cover if enough is exposed
Is it reasonably certain these are the only longitudinal bars in the bridge?
Yes
No
Use magnetometer to find bars and determine spacing and cover
Did magnetometer pick up the bars?
Yes
No
Where on slab was test performed?
Bottom
Top
Remove portion to measure spacing and cover or use ground penetrating radar
Asphalt layer or just concrete?
Asphalt
Concrete
Remove asphalt and test again
Remove portion to measure spacing and cover or use ground penetrating radar
If applicable, compare results from old plans and exposed bars with physical test
Make final recommendation on bar cover and spacing


Start
Any historical information on bridge?
No
Yes
Download archived standard drawings for appropriate bridge age
Is concrete mix listed in plans?
Yes
No
Record design strength
Download archived Bridge Design Manual, mix will be listed
Use rebound hammer or coring to determine *in situ* concrete strength
Make final recommendation for concrete strength



Start
Any historical information on bridge?
Yes
Download archived Bridge Design Manuals from ODOT website
See Unit Stress Section
No
Do you want to investigate yield strength?
No
Use f_y=33 ksi
Yes
Is f_s = 15 or 16 ksi?
No
Use f_y = 40 ksi or investigate yield strength
Yes
Any exposed bars?
Yes
No
Are mill marks visible and do they match known bar?
Yes
No
Can you cut a 2-3 foot long section that will fit in a tensile testing machine?
Yes
Perform full size tension test to determine yield
Is it possible to perform hardness testing using portable tester to determine yield
No
Yes
No
Can you cut a 7-8 inch section?
Yes
Get samples machined to meet ASTM E8 standard specimens
Perform small scale tension testing to determine yield
No
Can you cut a 3-4 inch section?
Yes
Do you have access to a lathe to machine sample?
Yes
Machine sample and perform compression testing to determine yield
No
No
Perform hardness testing to determine yield
Make final recommendation on yield strength

VERIFICATION

- Two one day field studies
  - Studied bridges in Fayette County where plans were available. Plans were not shown to the research team until after results were obtained.
  - Studied bridges in Jefferson County where plans were not available to determine if the methodology was practical.

VERIFICATION

- Fayette County
  - Field results confirmed accuracy of magnetometer and rebound hammer.
  - Some difficulties with the magnetometer on bridges where the cover was large.
  - If bars are skewed, the magnetometer scan must follow the skew.

VERIFICATION

- Jefferson County
  - It was possible to get good quality scans of the rebar with the magnetometer.
  - On all the bridges, deteriorated areas confirmed the magnetometer readings.

Property	Avg. Error		
	Literature Search	Survey	Experimental
Concrete Strength	30%-40%	1500 psi	24.2%
Cover (Effective Depth)	0.25 inches	0.50 inches	0.22 inches
Bar Size	1 bar size	1 bar size	1 bar size
Bar Spacing	0.375 inches	0.50 inches	0.384 inches

CONCLUSIONS

- It is possible to determine the properties of a slab bridge with sufficient accuracy for rating even if the plans are lost.
- Historical records can sometimes provide information on materials used at the time if the approximate date of construction is known.

CONCLUSIONS

- Concrete strength is most accurately found from cores.
- Concrete strength can be found using NDT techniques such as a rebound hammer. The accuracy is +/- 1500 psi.
- Concrete strength is not an important parameter and actual strengths usually exceed the design strength.

CONCLUSIONS

- Magnetometers can determine the cover distance to the reinforcing bar.
  - Accuracy decreases with increasing cover.
  - Accuracy is within 10% for cover less than 1.75 inches.
  - For larger covers, the accuracy may decrease to +/- 25%.
  - For large cover values, GPR is needed.

CONCLUSIONS

- Magnetometers can find bar spacing.
  - Accuracy decreases with increasing cover.
  - Bars spacing is generally within +/- 3/8 inch.
  - Averaging multiple scans provides better results.
  - Bar spacing can often be verified from some other means such as finding a deteriorated area.

CONCLUSIONS

- Magnetometers can find bar size.
  - Accuracy decreases with increasing cover.
  - Bars size is usually +/- one bar size.
  - Bar size can often be verified from some other means such as finding a deteriorated area.

CONCLUSIONS

- Yield strength can be estimated from
  - Historical record
  - Mill marks
  - Tension tests (AASHTO T68 or T244)
  - Compression tests
  - Hardness

REPORT

http://www.dot.state.oh.us/groups/oril/Documents/Projects/structures_synthesis.html

THANKS TO THE TAC PANEL

- Fred Pausch (County Engineer's Association of Ohio),
- Jim Branagan (Jefferson County Engineer),
- Rui Liu (Kent State University),
- Steve Luebbe (Fayette County Engineer and Bearcat),
- Eric Steinberg (Ohio University)
- Amjad Waheed (Ohio Department of Transportation).

Questions??