FIELD TESTING AND PERFORMANCE OF METAL CULVERTS IN OHIO

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RESEARCH OBJECTIVES & OUTLINE

- ODOT maintains thousands of culverts in Ohio
- In-house program *CMP-Excel* is used for evaluation

Objectives:

- Review ODOT's culvert database
  (Parameters: geometry, loading, age, soil depth etc.)
- Perform field testing of 40 culverts in Ohio
- Validate and verify *CMP-Excel* using test data
- Model and analyze culverts (e.g., CANDE, FLAC)
- Compare the test data with analytical results
- Propose new methods/recommendations

DO CULVERTS FAIL? CONSEQUENCES

Vail, CO

Bakersfield, CA

Cuyahoga Co, Ohio

RESEARCH APPROACH

Experimental Research:

- Develop a test matrix
  - Instrumentation: strains and displacements
  - Loading: standard loading truck
  - Static and dynamic tests

Analytical Research:

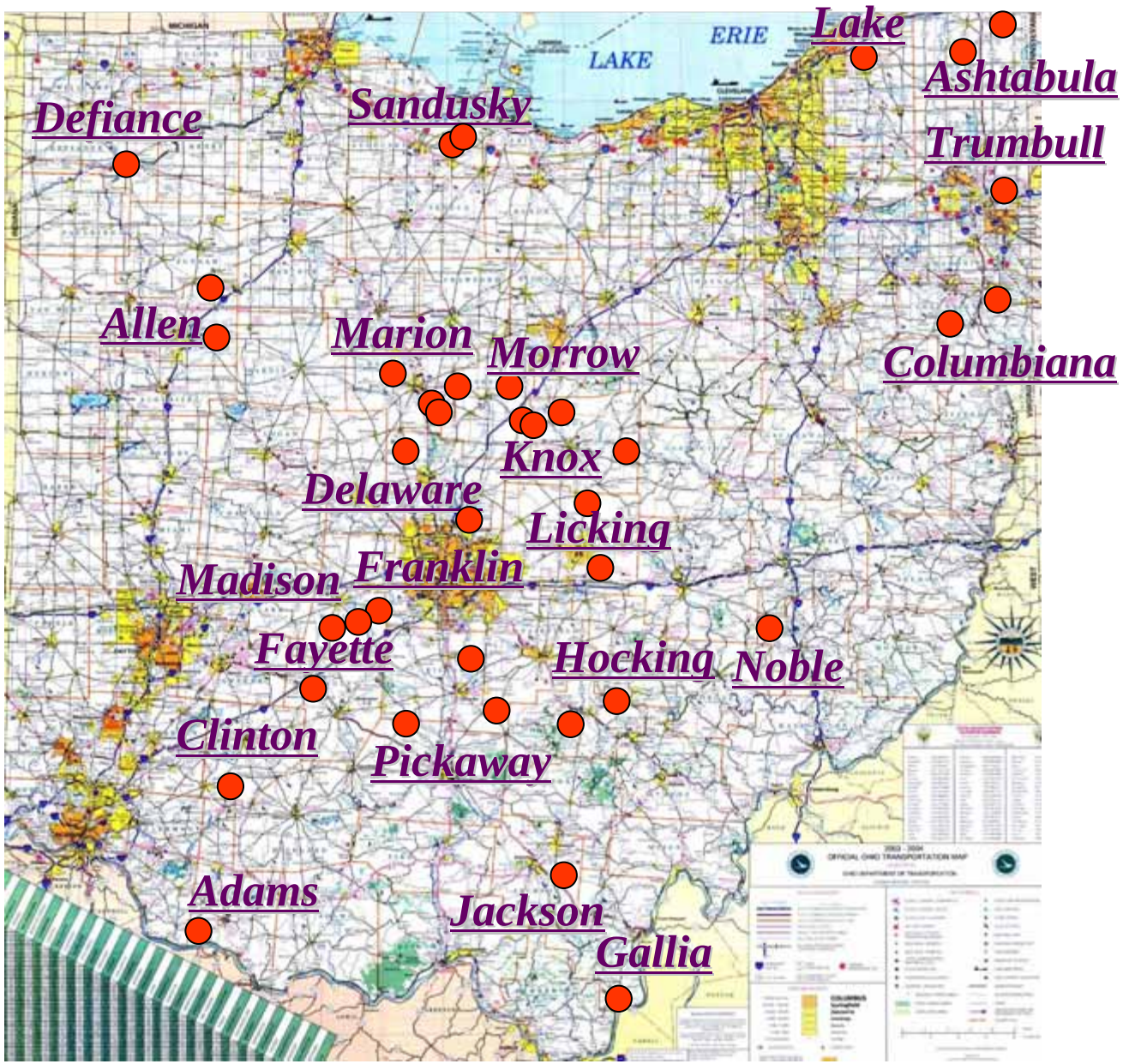
- Model and analyze the test culverts
  - use simplified 2-D models (CANDE)
  - equivalent line loading (AASHTO)
  - use detailed 3-D models (FLAC-3D)
- Evaluate the in-house program, *CMP-Excel*

TEST CULVERTS

Number of culverts tested so far: 38

- **Backfill height: 0.9 to 24.5 ft**
- **Span length: 11 to 21 ft**
- **General appraisal number: 2 to 9**
- **ADT: 580 - 12420**
- **Year built: 1938 - 1997**
- **Different test locations in Ohio**

TEST SITE LOCATIONS



INSTRUMENTATION

Direct displacement measurements (inside culvert):

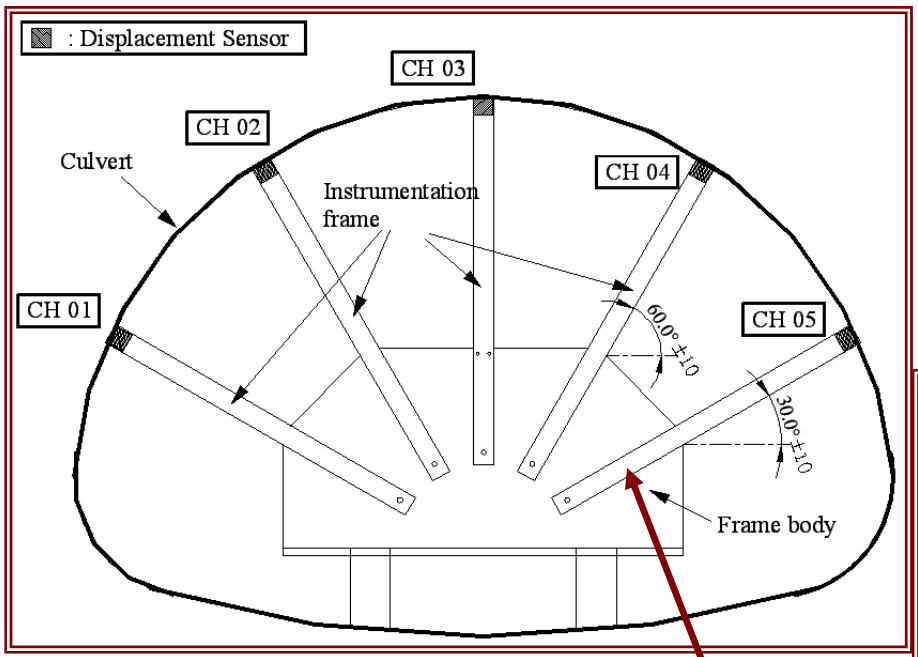
- Vertical and diagonal directions
- Displacement sensors attached on an adjustable frame
- 5 channels (CH 01 - CH 05)
- CH06 is used for slippage between culvert plates

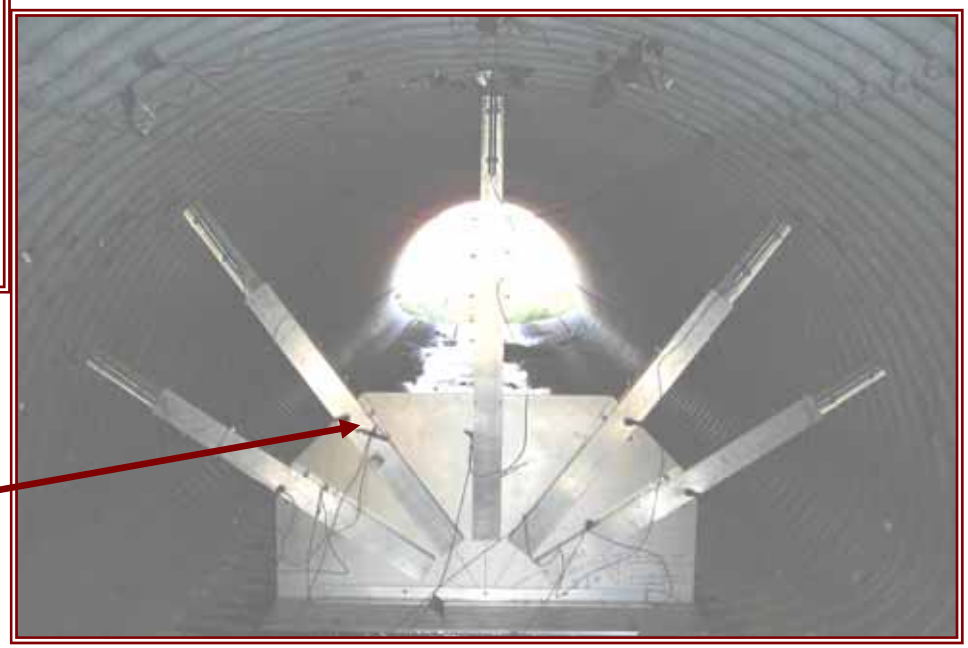
Strain measurements:

- Information about strains and stresses
- Strain gauges attached on the inside surface of culvert
- Longitudinal and transverse directions
- 14 channels (CH 07 - CH 20)

DISPLACEMENT MEASUREMENTS:

Locations of the 5 displacement sensors (CH 01 – CH 05)

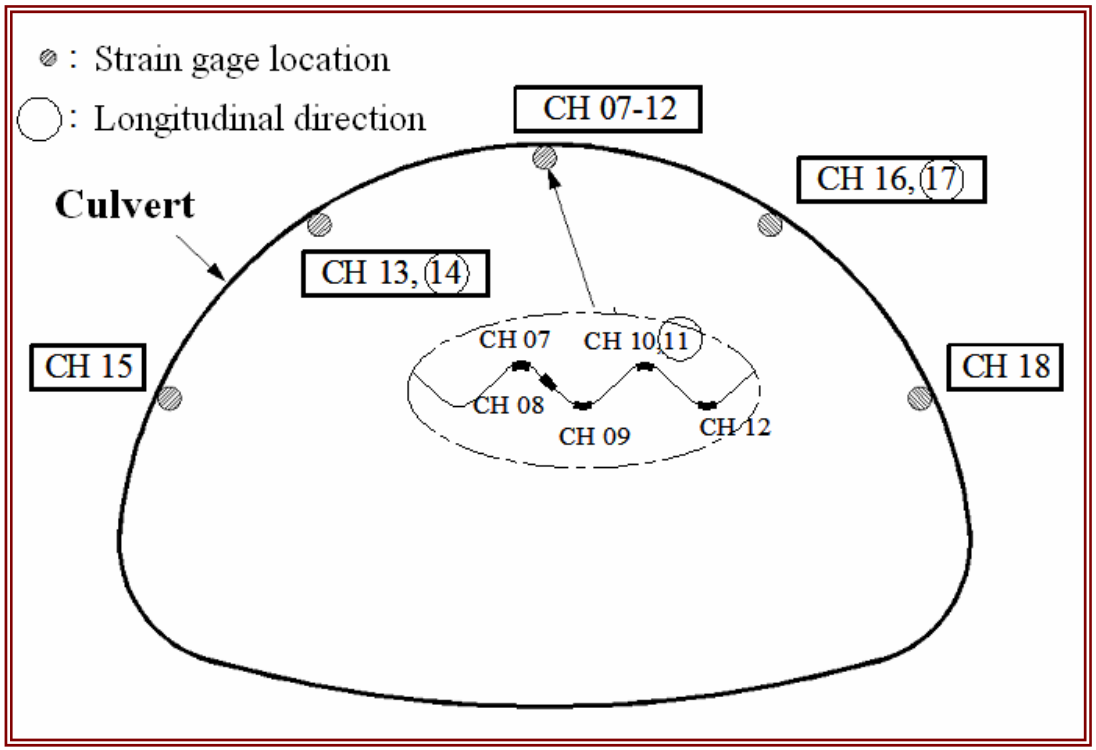


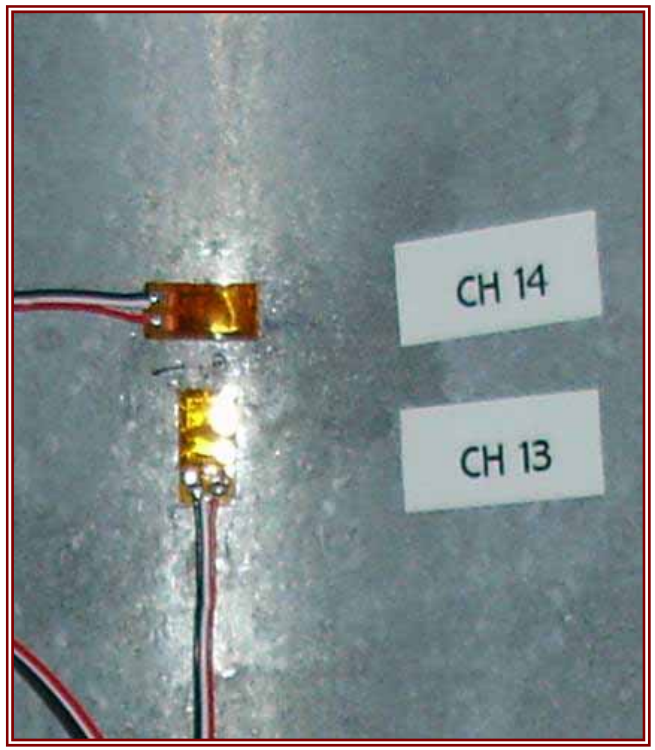


Adjustable instrumentation frame

STRAIN MEASUREMENTS

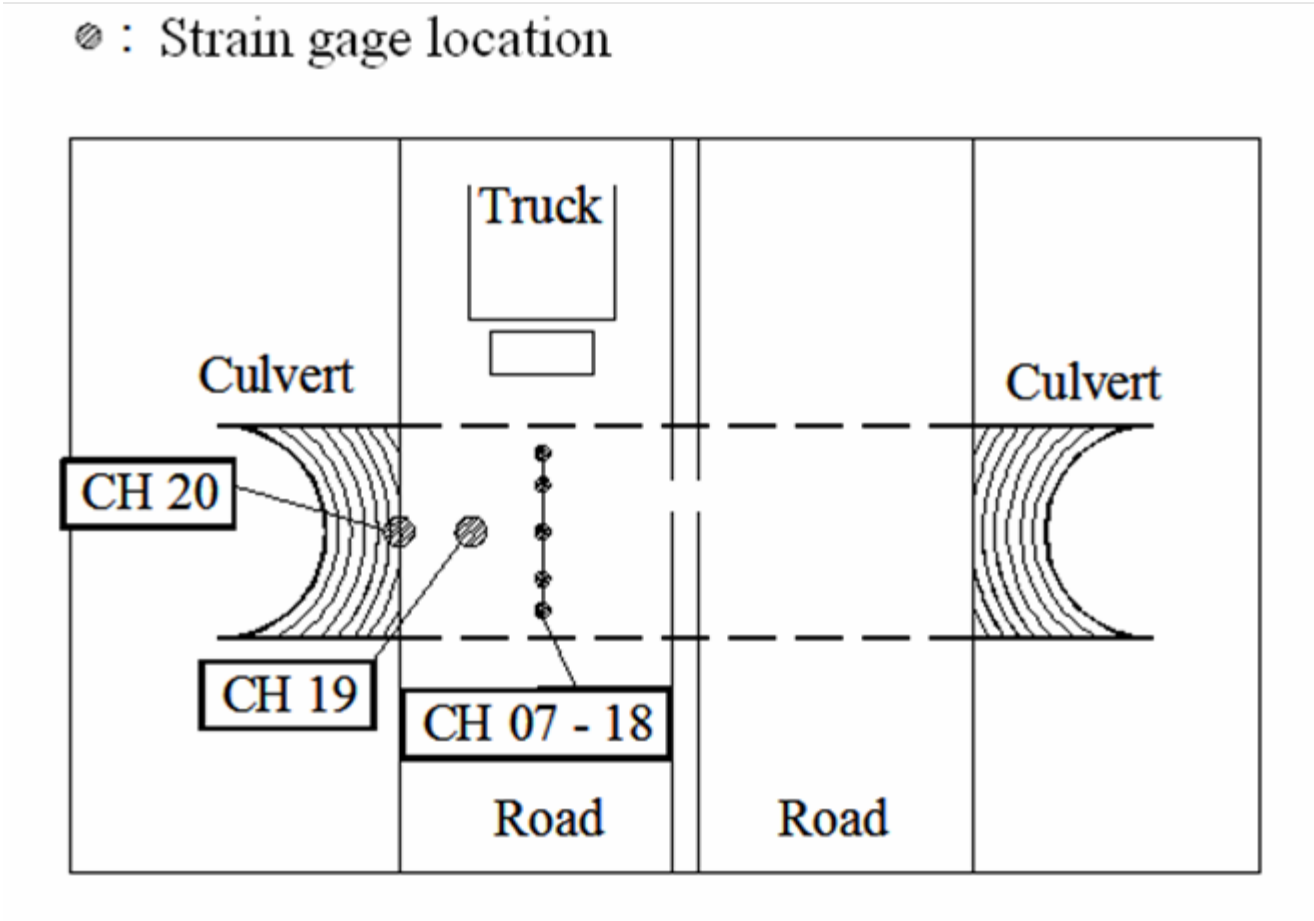
Locations of the 12 strain gages (CH 07 – CH 18)





STRAIN MEASUREMENTS

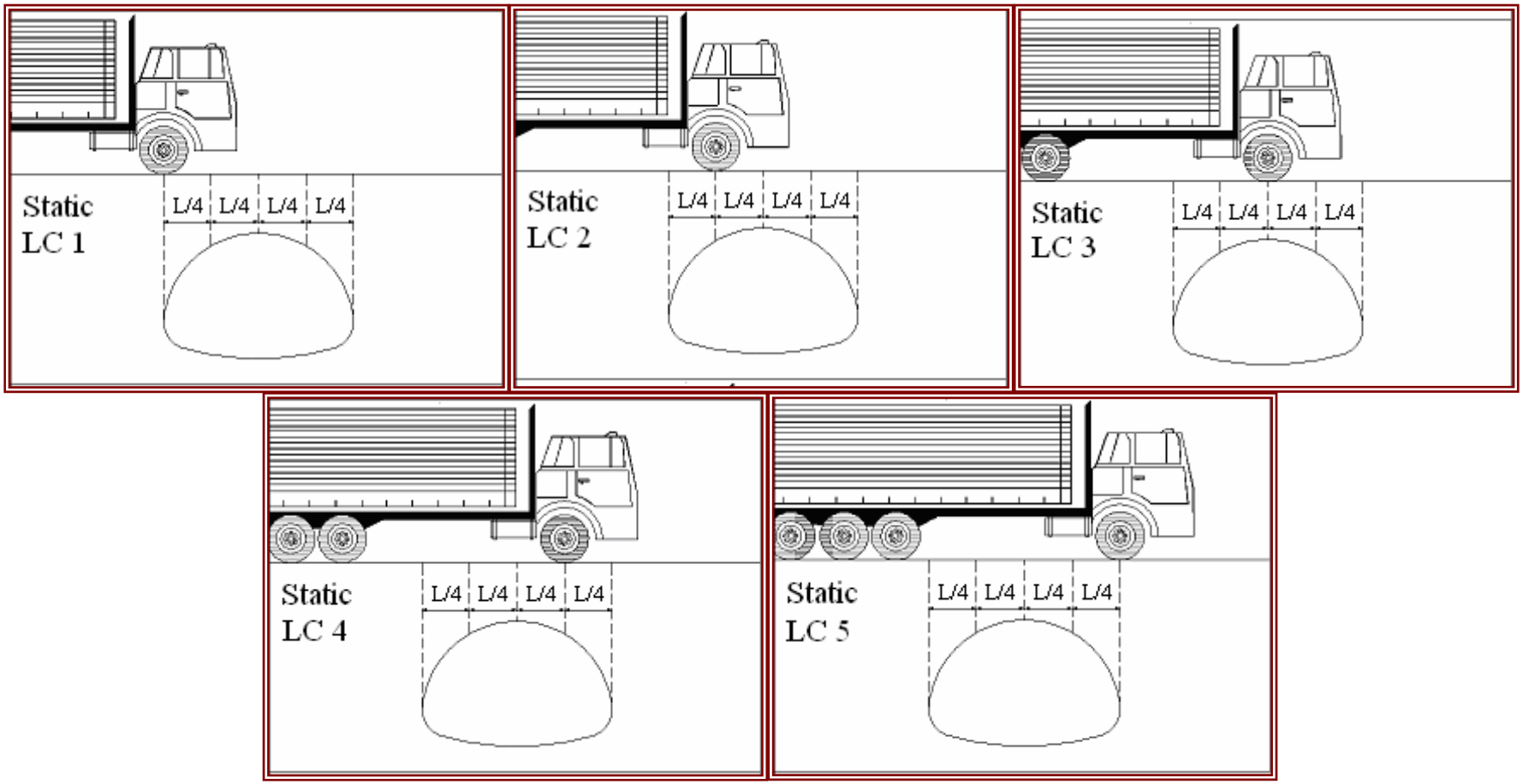
Gauge locations along culvert length (plan view): CH 07–CH 20



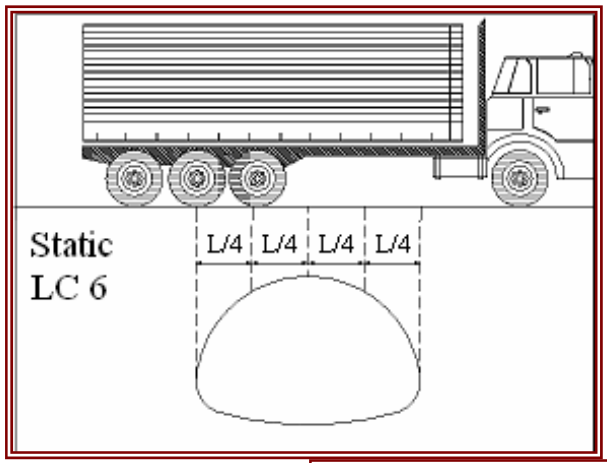
LOADING TRUCK

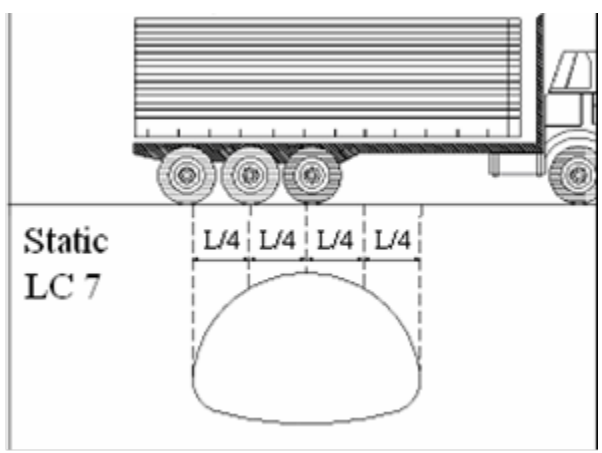
Total weight: 54-89 kips
Steering axle: 12-27 kips
Drive axles: 16-31 kips

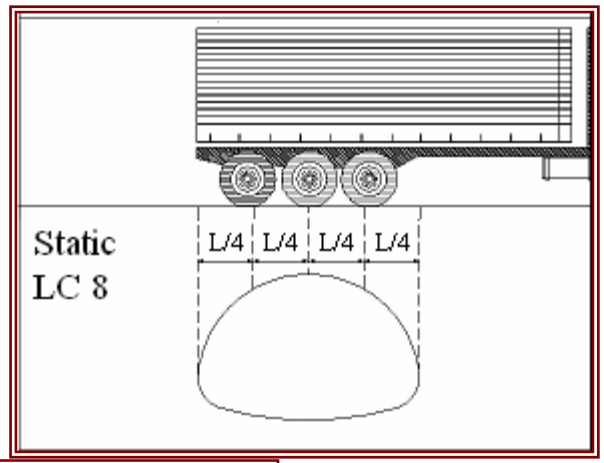
STATIC LOAD POSITIONS

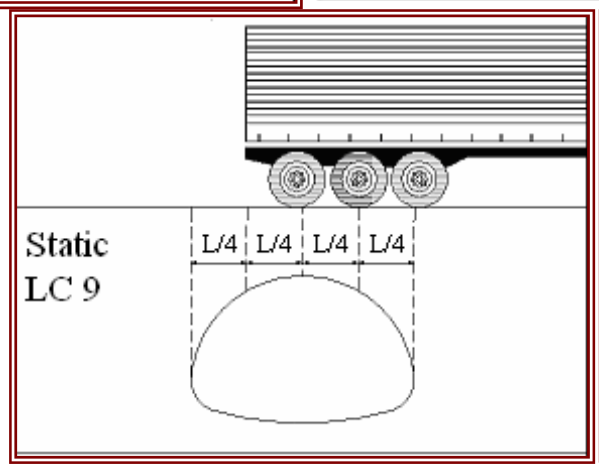


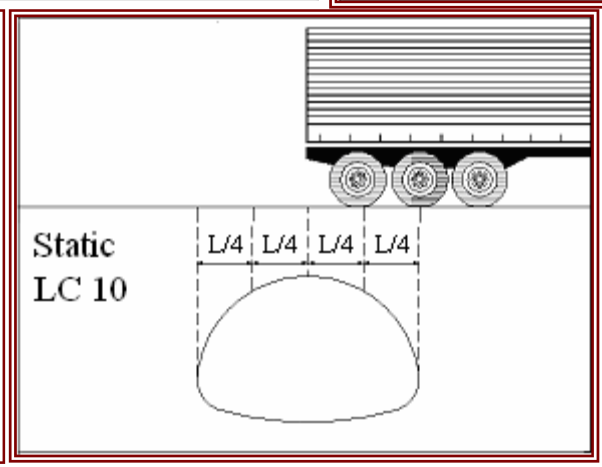
STATIC LOAD POSITIONS











STATIC TESTS

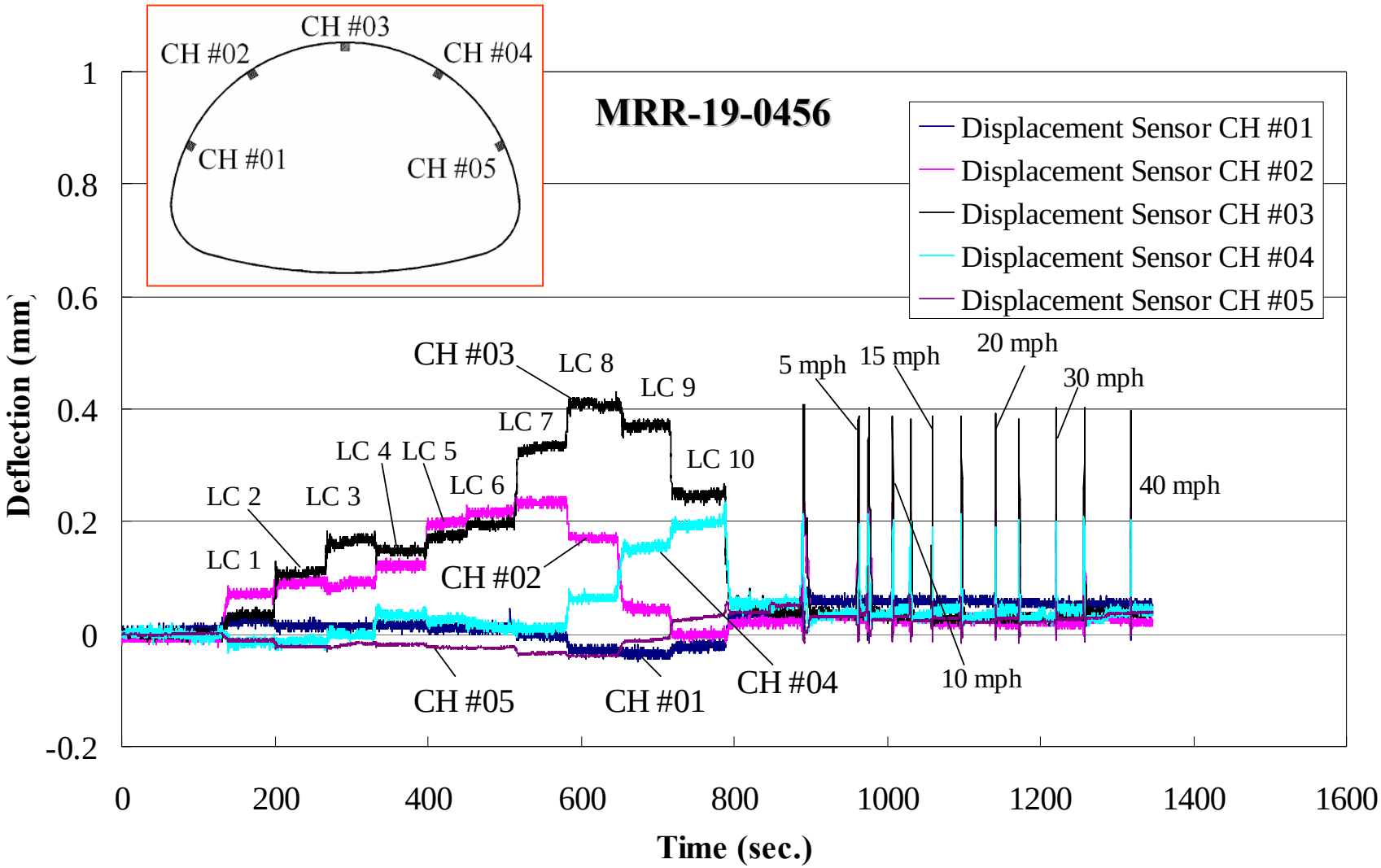
- **Maximum displacement: 2.25 mm (0.09 in.)**
  (very shallow culvert - 1 ft deep)
- **Maximum strain: 108×10^{-6}**
  (very low appraisal number, 3)

DYNAMIC LOADING

Truck driving over the culvert at speeds:

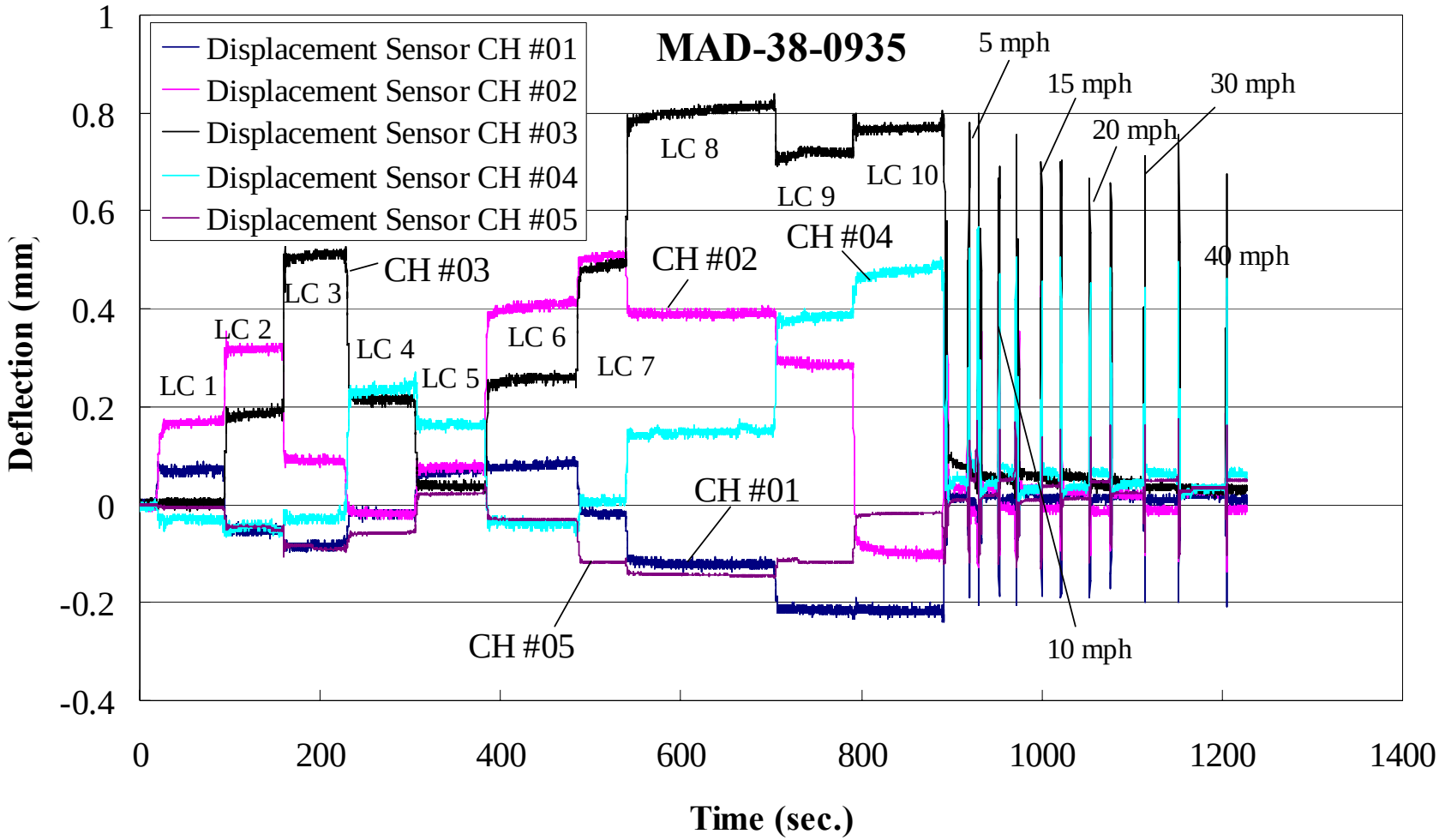
- **5 - 10 – 15 – 20 – 25 – 30 mph**
- **Legal speed limit**

SAMPLE TEST RESULTS



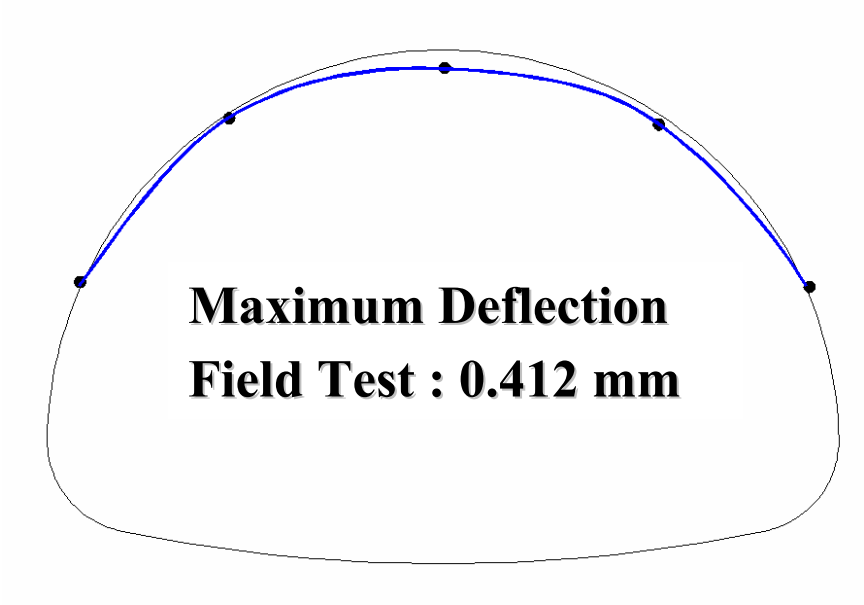
Route 19, SLM 0456, Morrow County

SAMPLE TEST RESULTS

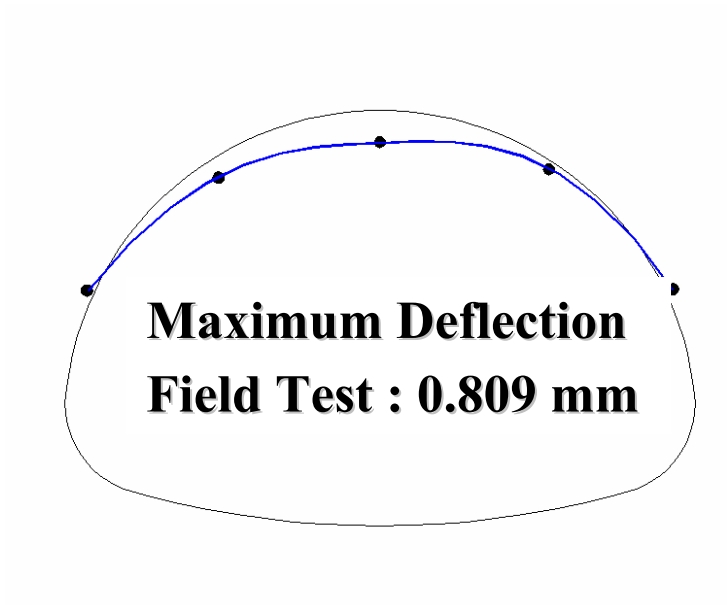


Route 38, SLM 0935, Madison County

DEFORMED SHAPES OF TWO CULVERTS

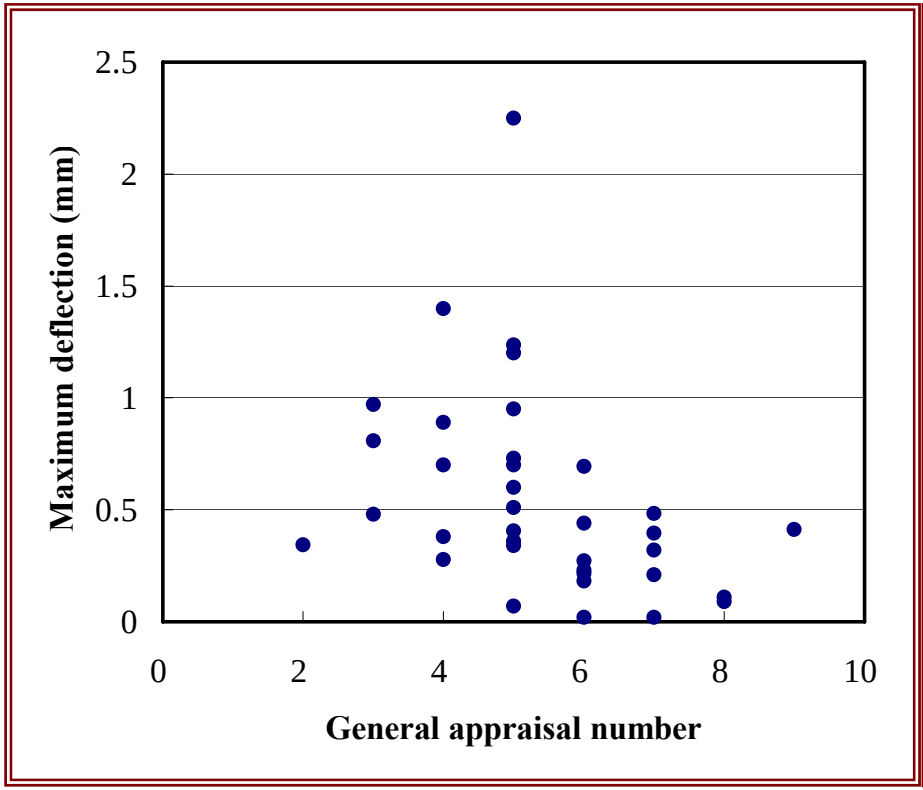


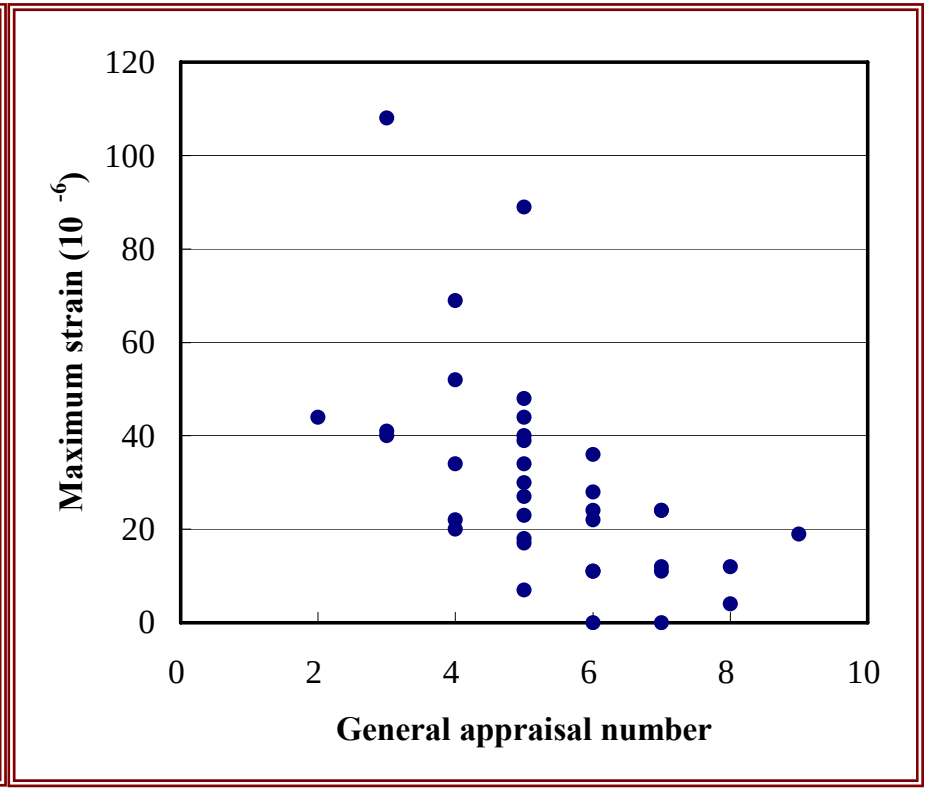
Route 19, SLM 0456,
Morrow County



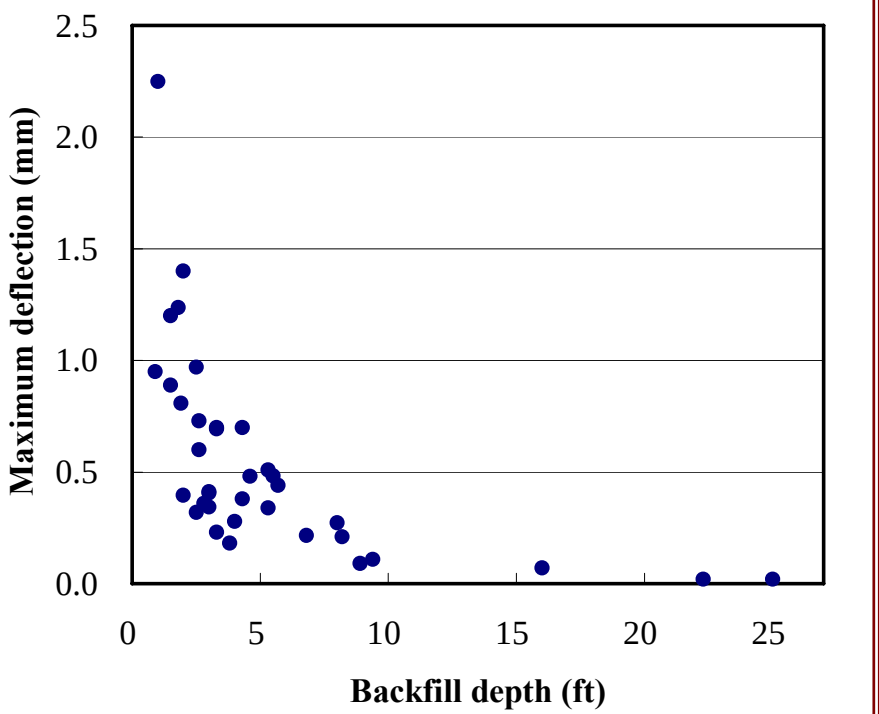
Route 38, SLM 0935
Madison County

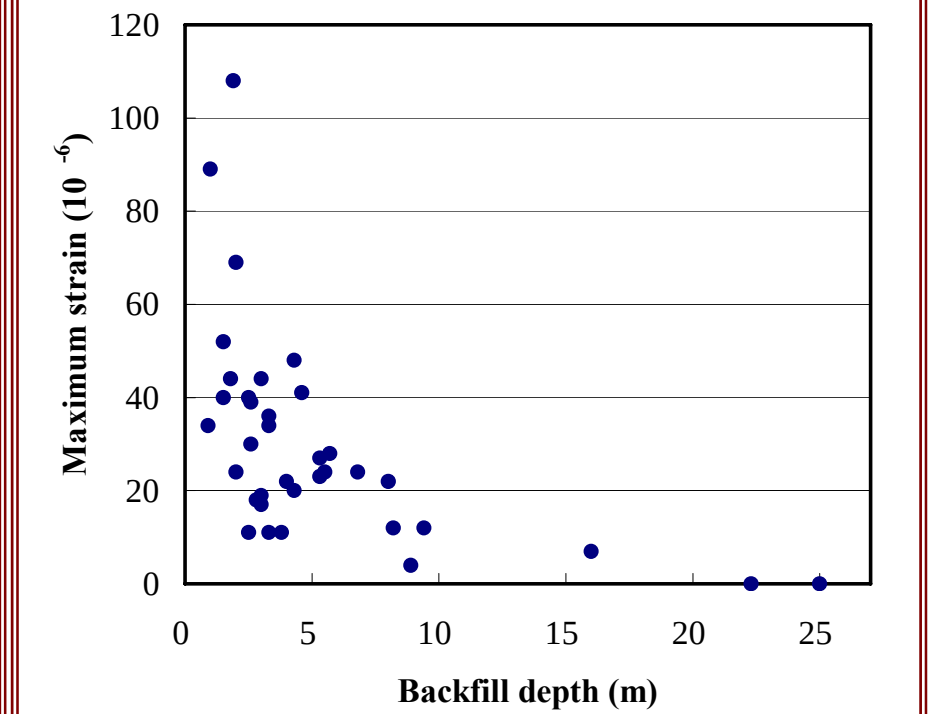
Deformation vs. General Appraisal Number





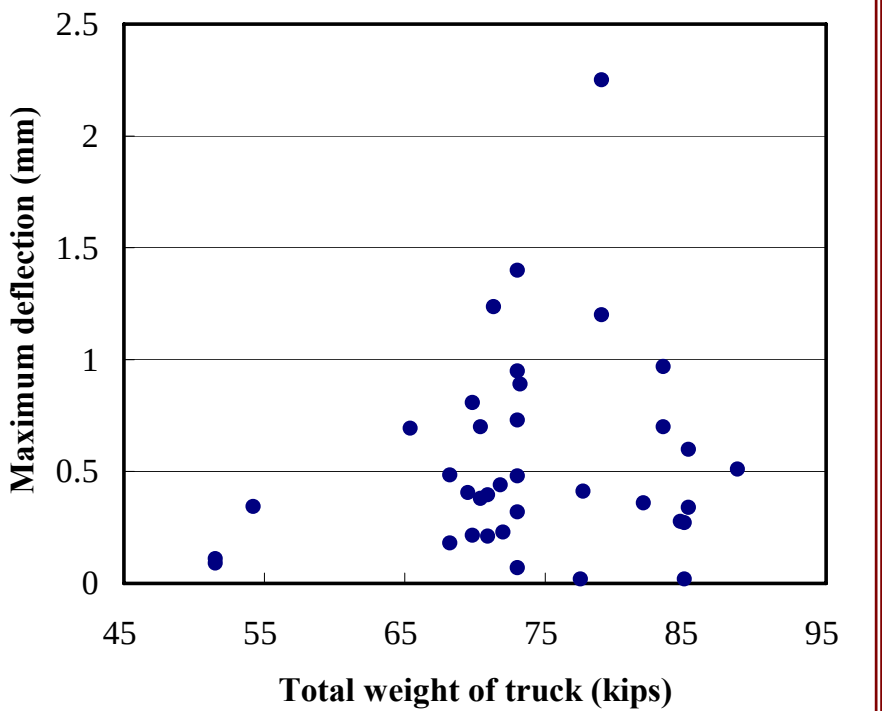
EFFECT OF BACKFILL DEPTH

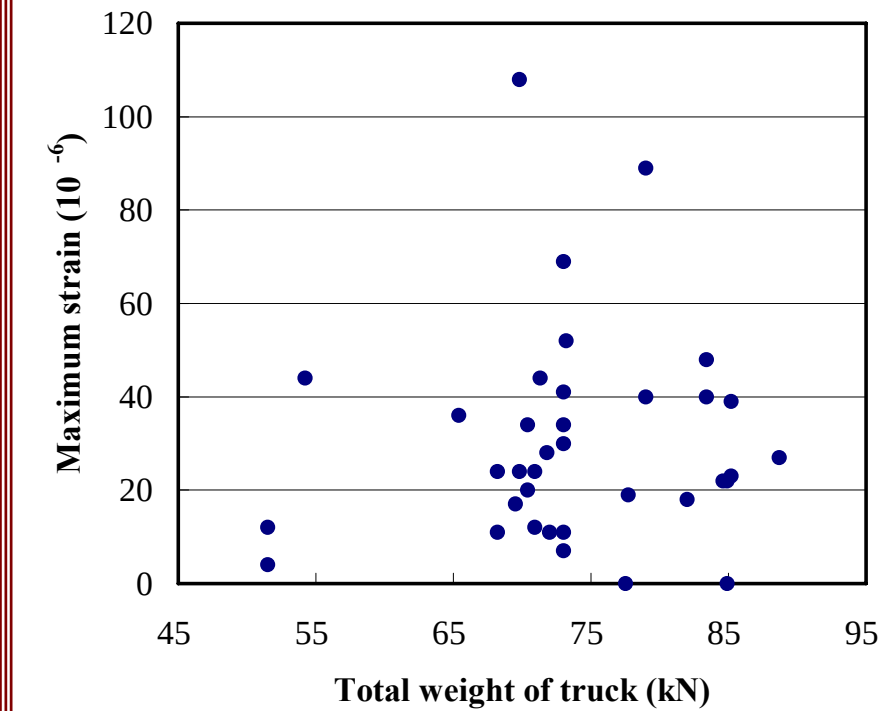




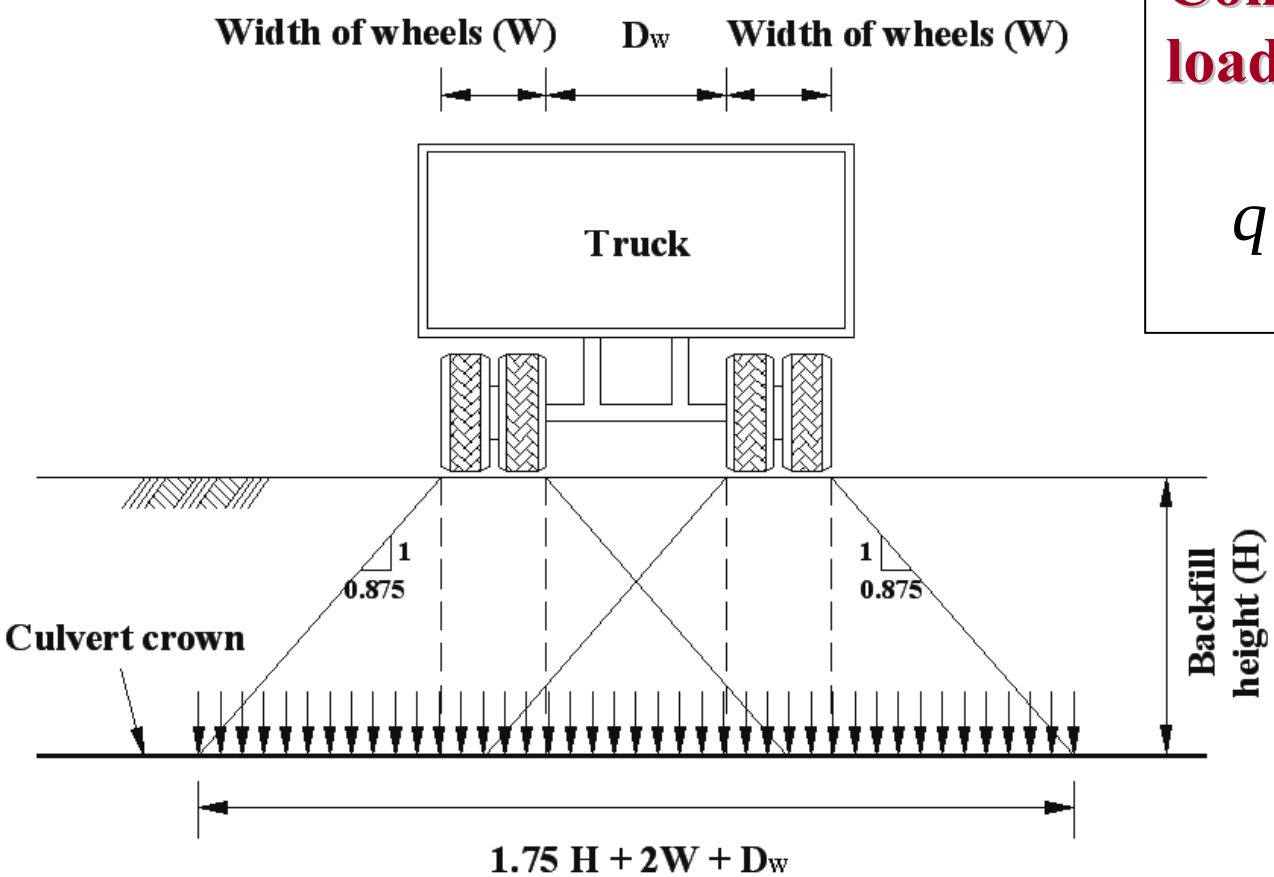
- Deformations seem to decrease with increasing backfill
- Very deep culverts do not feel the load

EFFECT OF TOTAL TRUCK WEIGHT





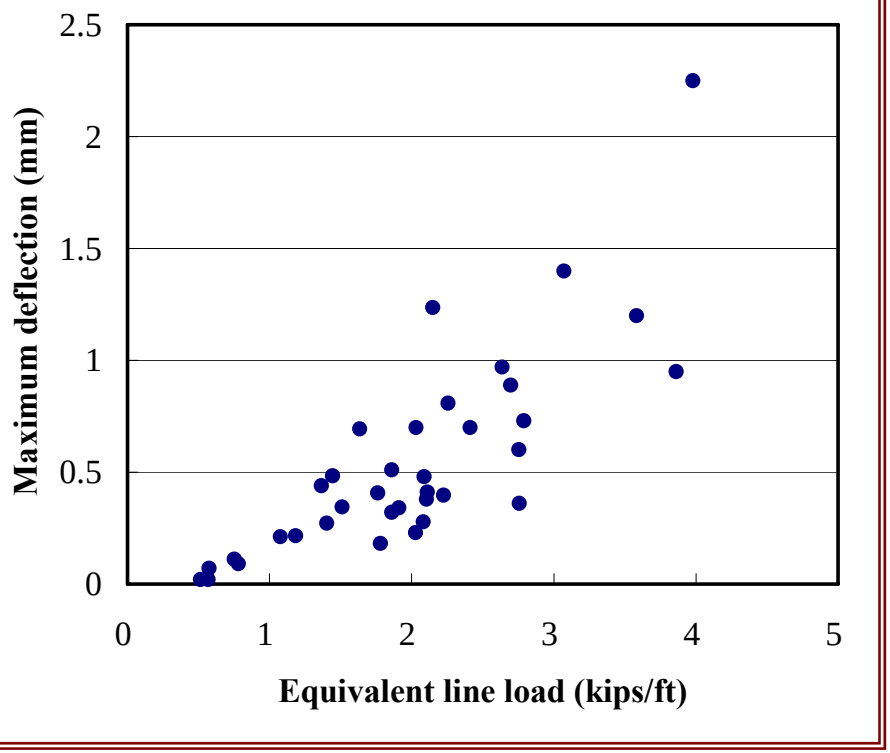
Equivalent Line Load (AASHTO)

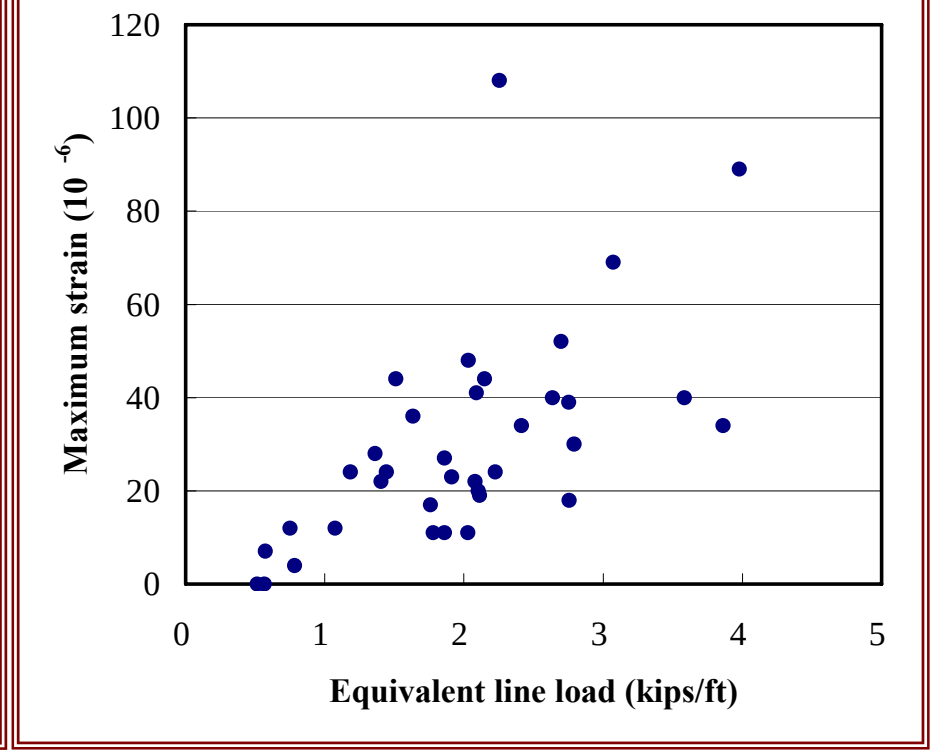


Conversion of total axle load, Q to line load, q:

$$q = \frac{Q}{1.75H + D_W + 2W}$$

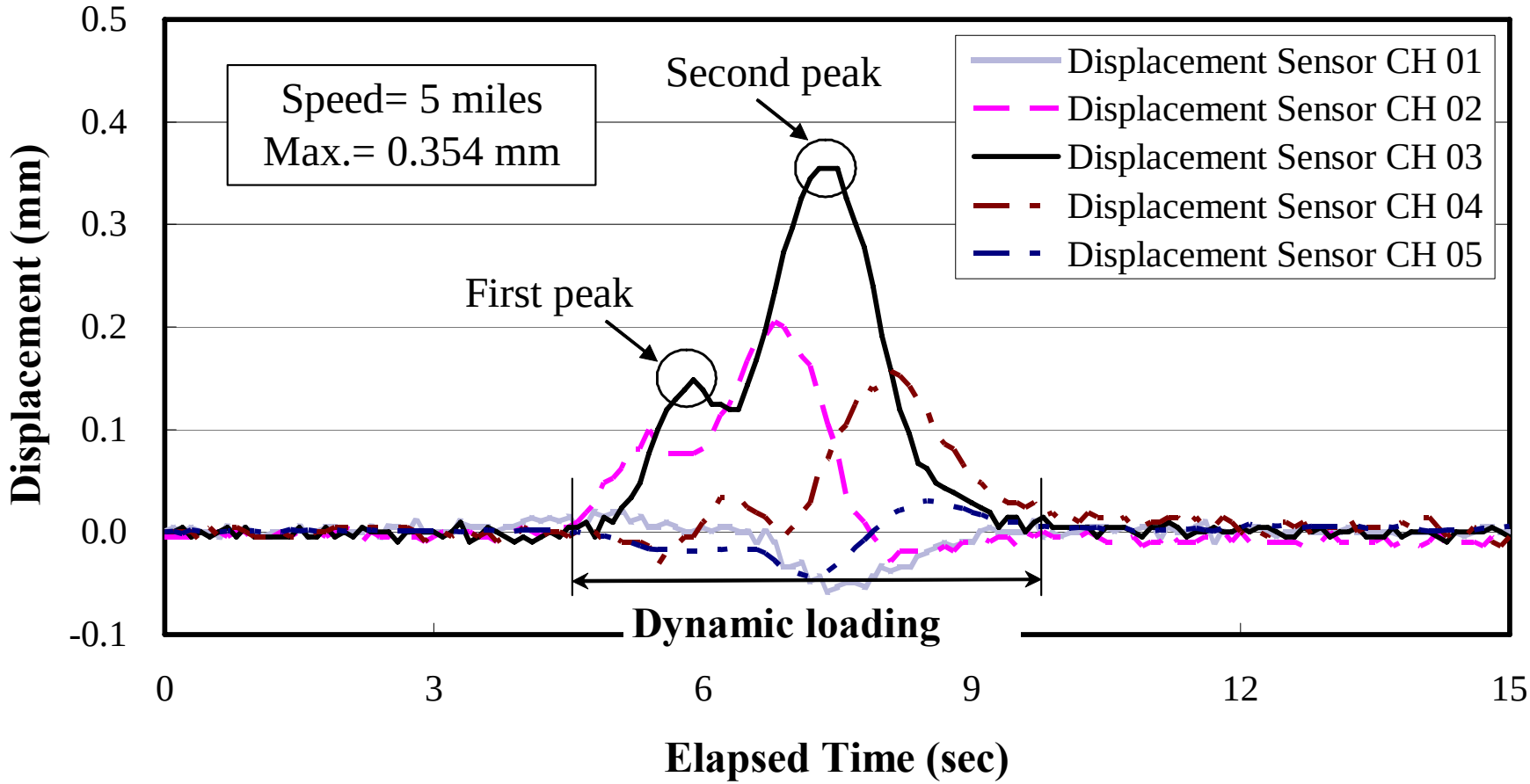
Effect of Equivalent Line Load (AASHTO)



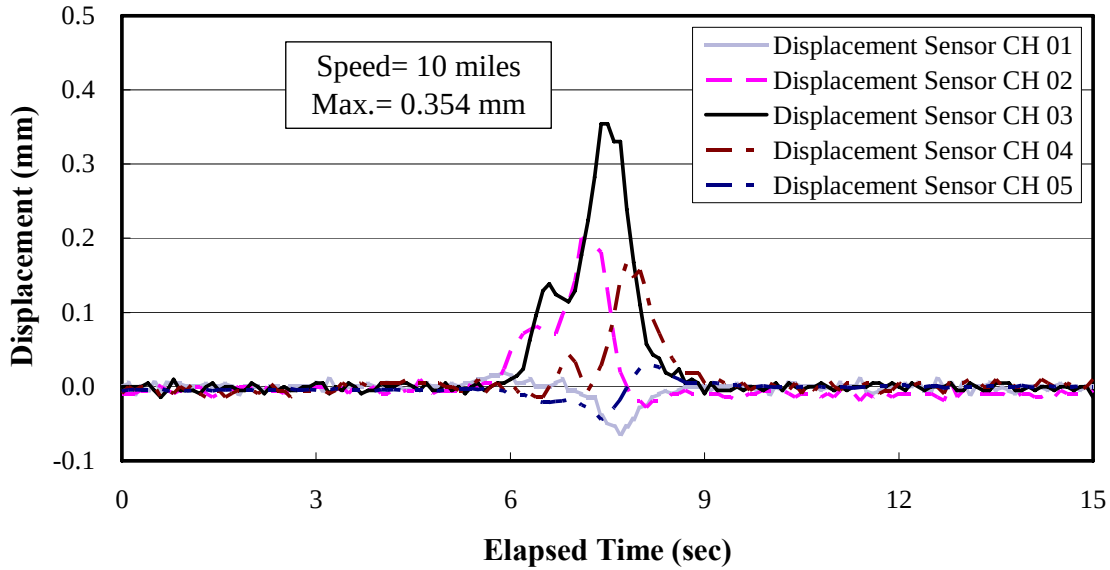


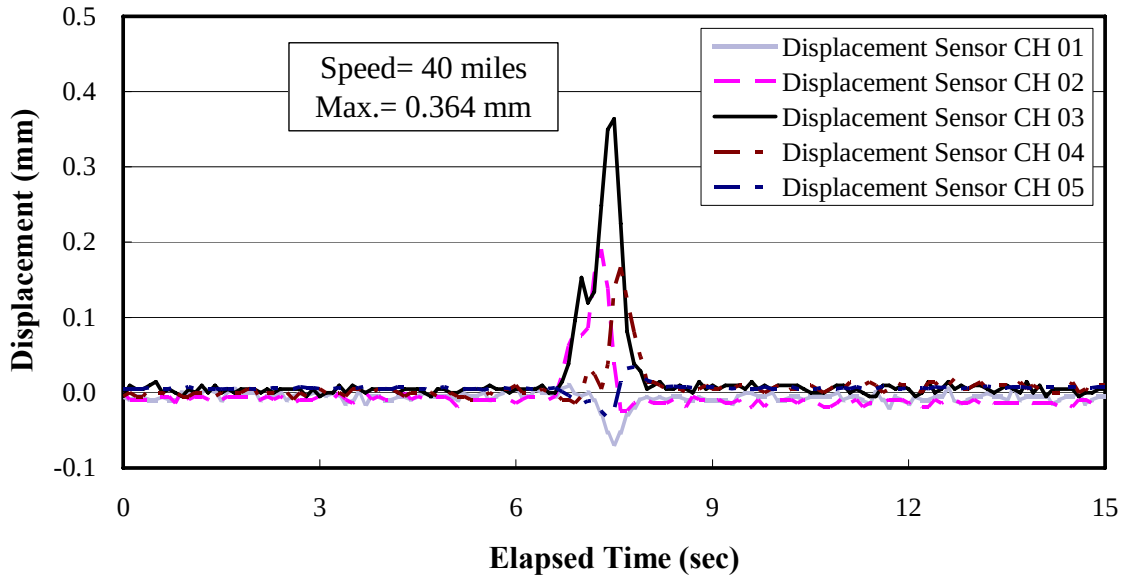
- Equivalent line load includes the effects of truck load and backfill height

DYNAMIC LOAD TESTS

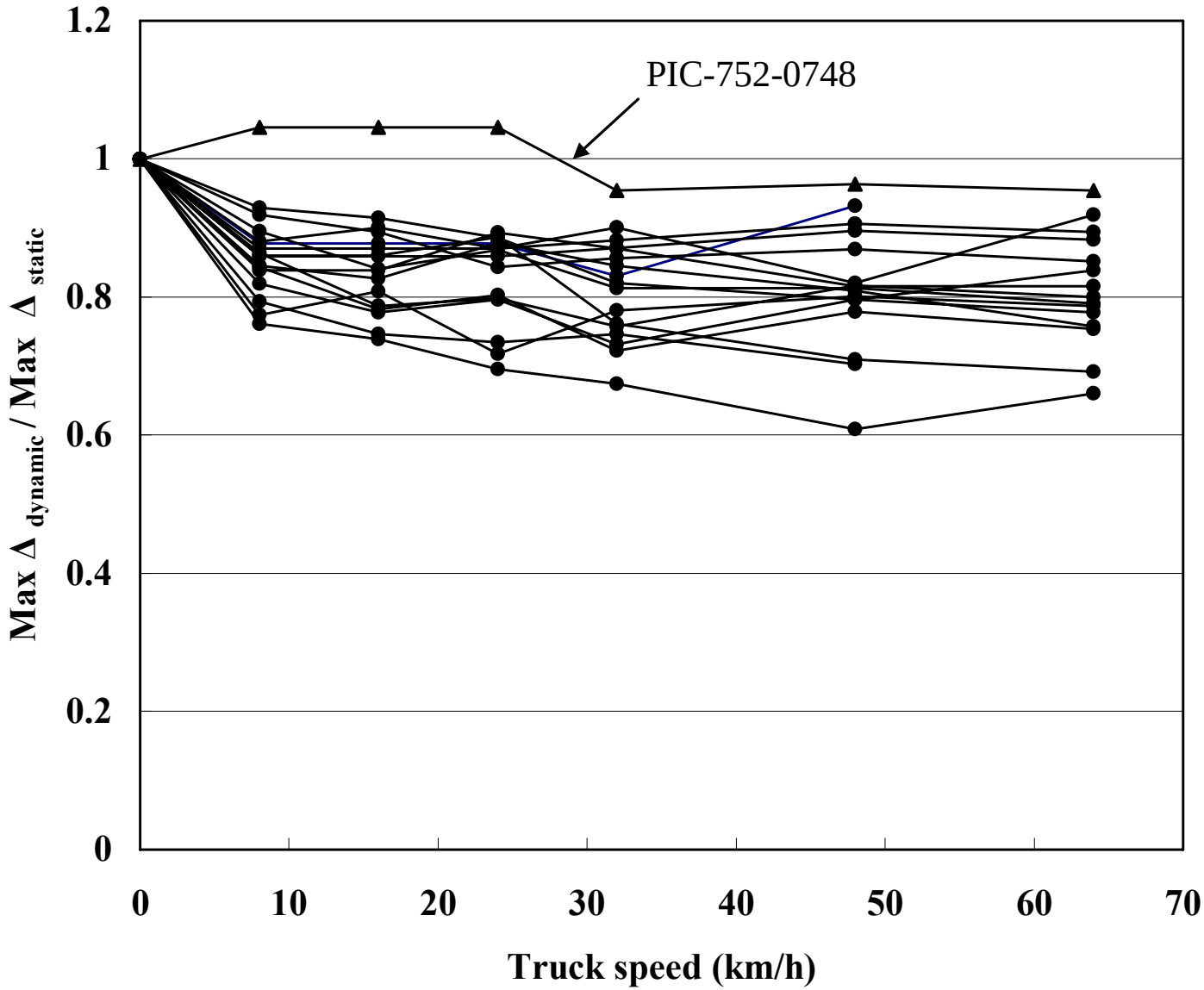


DYNAMIC TEST DATA





Maximum Deflection Ratio vs. Truck Speed



ANALYTICAL RESEARCH

2-D Modeling of culverts using CANDE program

- ➔ Plane-strain analysis
- ➔ Comparison of analysis results with field test data

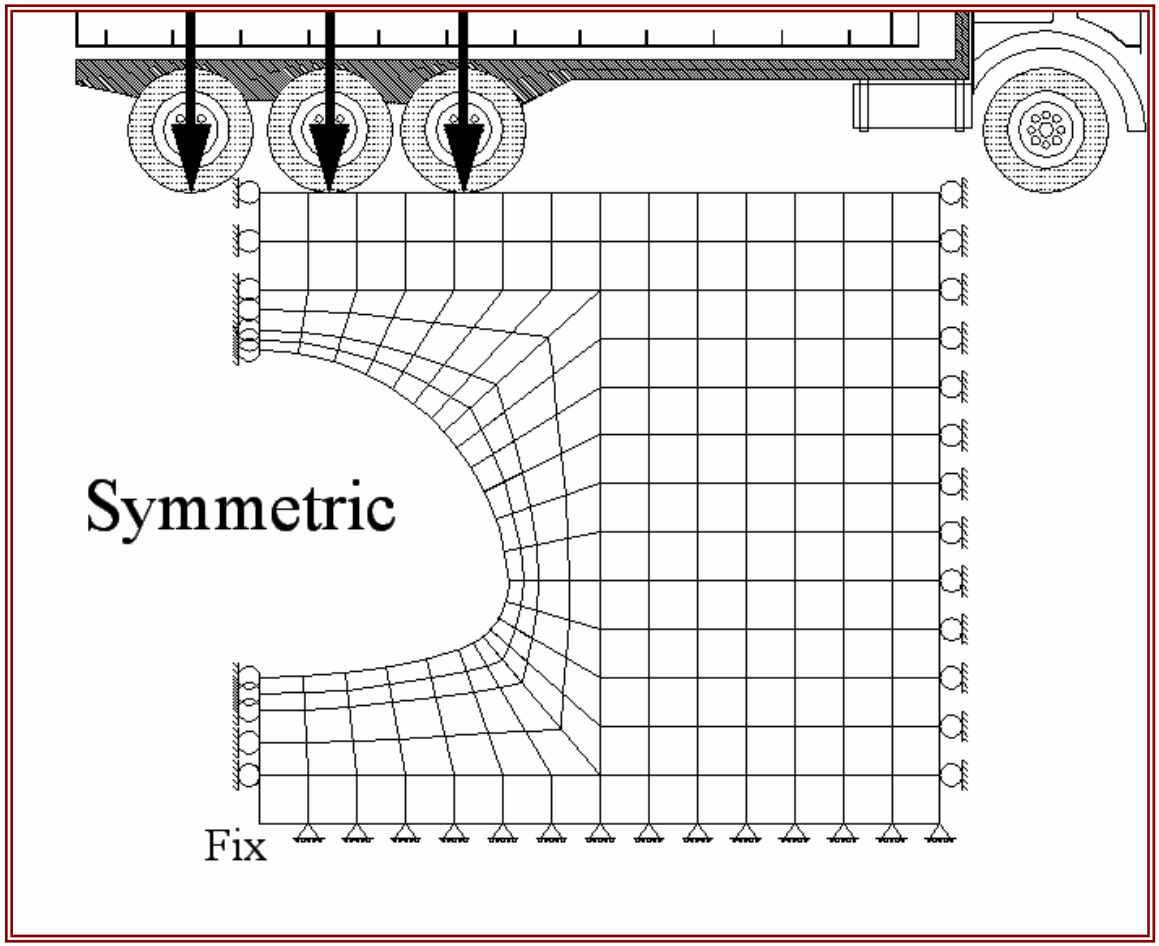
3-D Modeling of culverts using FLAC program

- ➔ FLAC: Fast Lagrangian Analysis of Continua
- ➔ 3-D analysis including the soil-structure interaction

Evaluation of ODOT's in-house spreadsheet, CMP-Excel

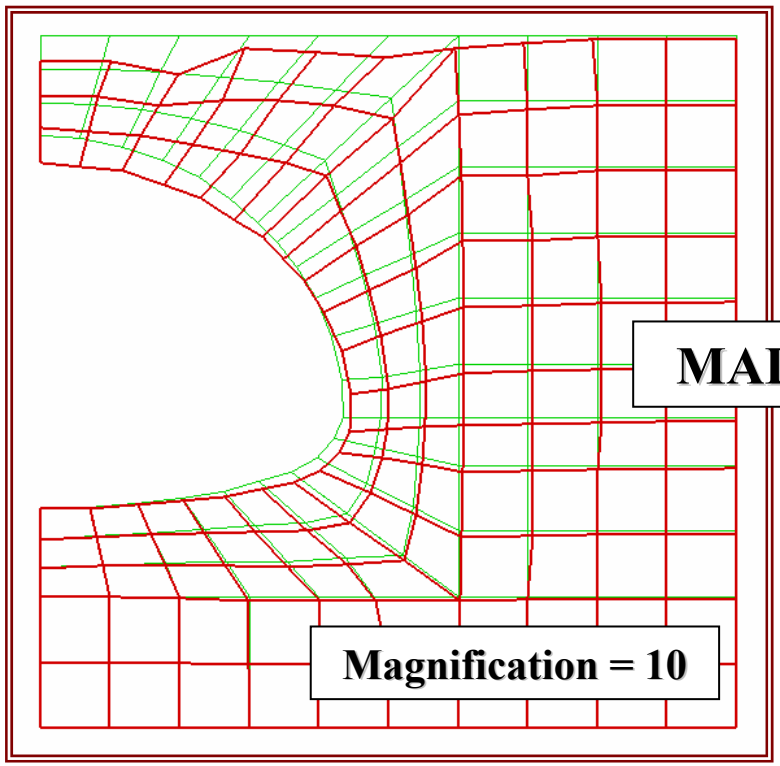
- ➔ Load rating evaluation program based on AASHTO & NSCSPA

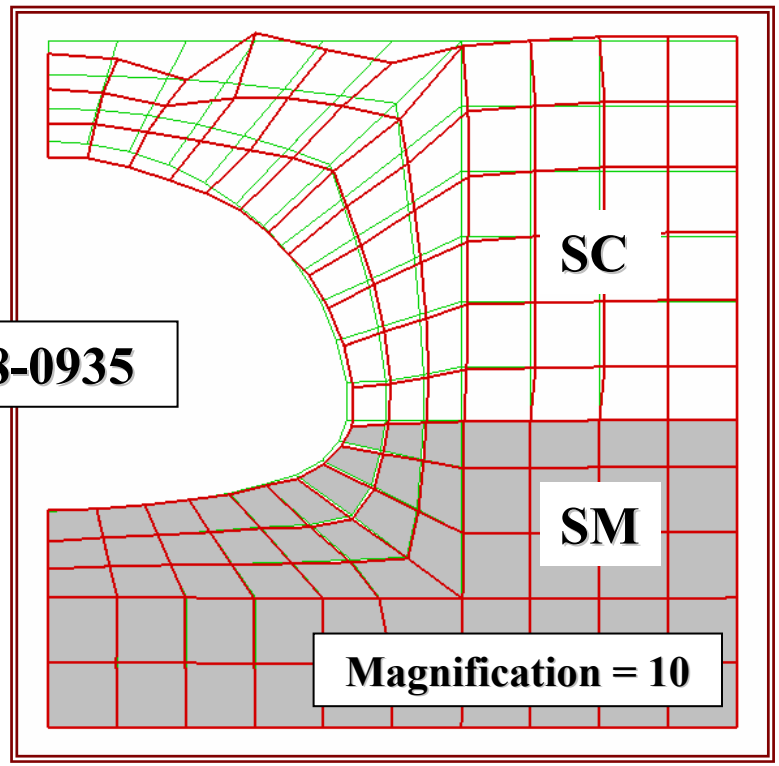
2-D CANDE MODEL



- Half model because of symmetry
- Roller boundary conditions on both sides
- Hinge boundary conditions at the bottom

CANDE ANALYSIS RESULTS





- Silty clayey sand (SC)
- Relative compaction: 100%

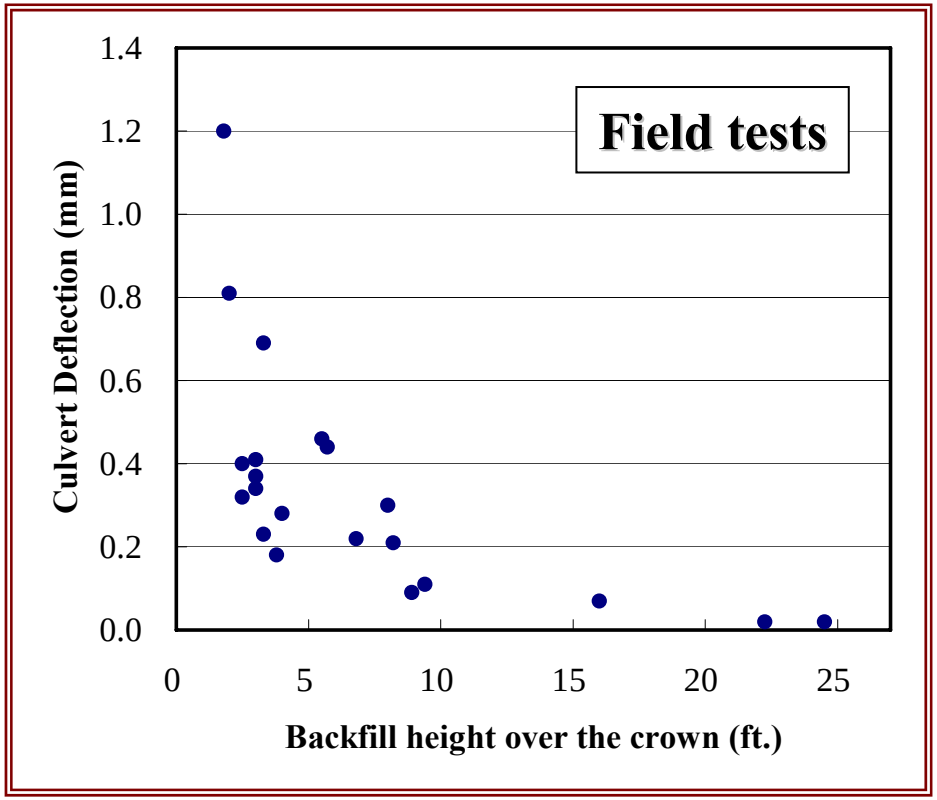
➔ Maximum displ.: 15.28 mm

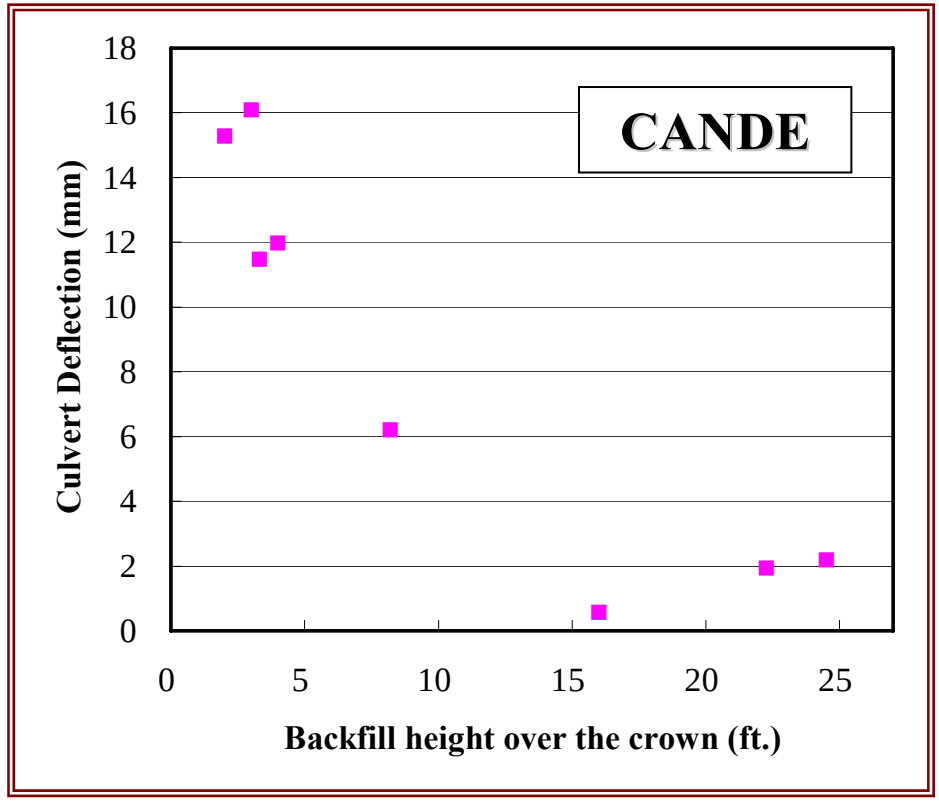
- SC + Silty sand (SM)
- Relative compaction: 100%

➔ Maximum displ.: 9.59 mm

Maximum displacement measured in the field: 0.81 mm

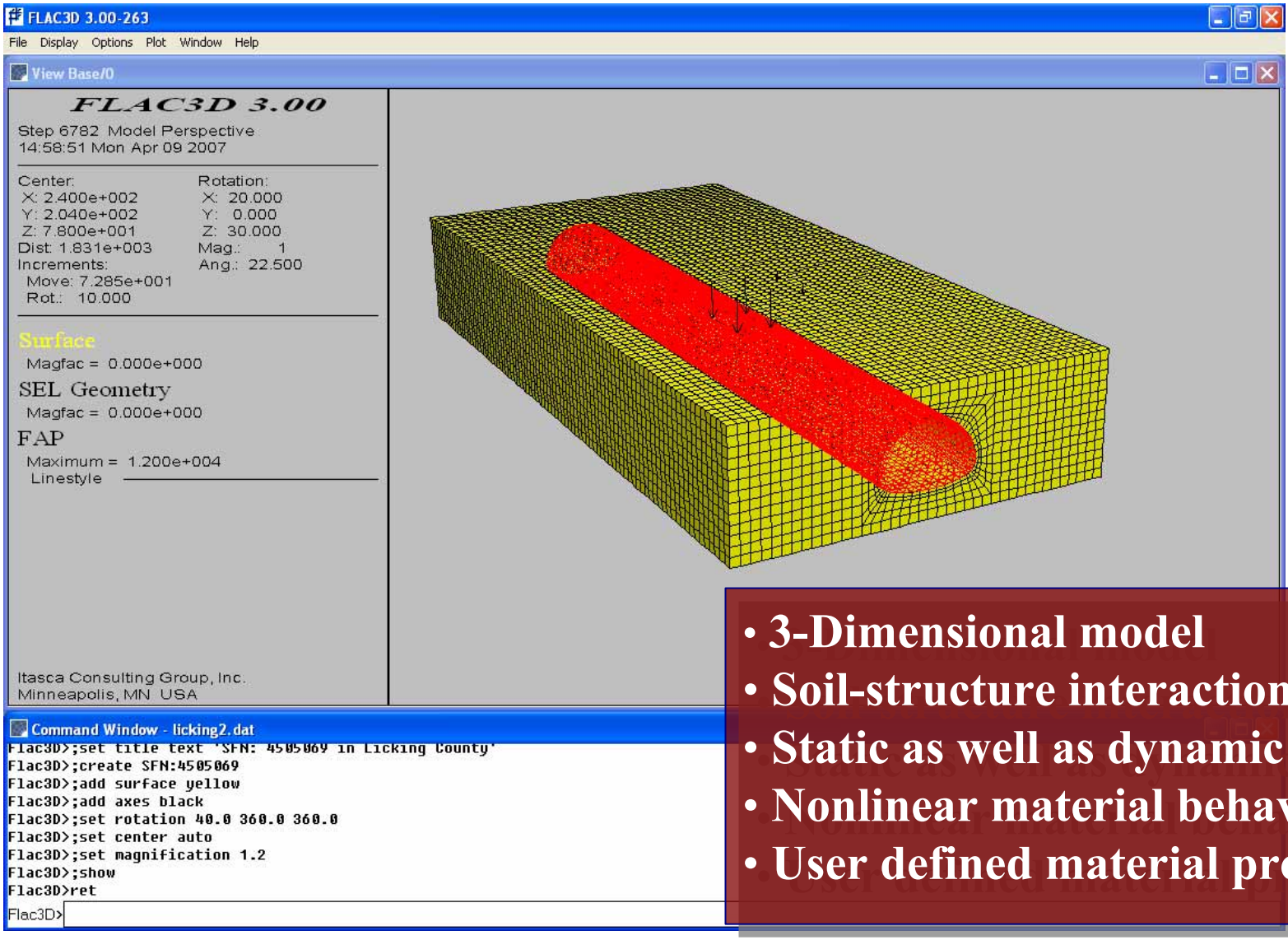
Analytical vs. Experimental Results





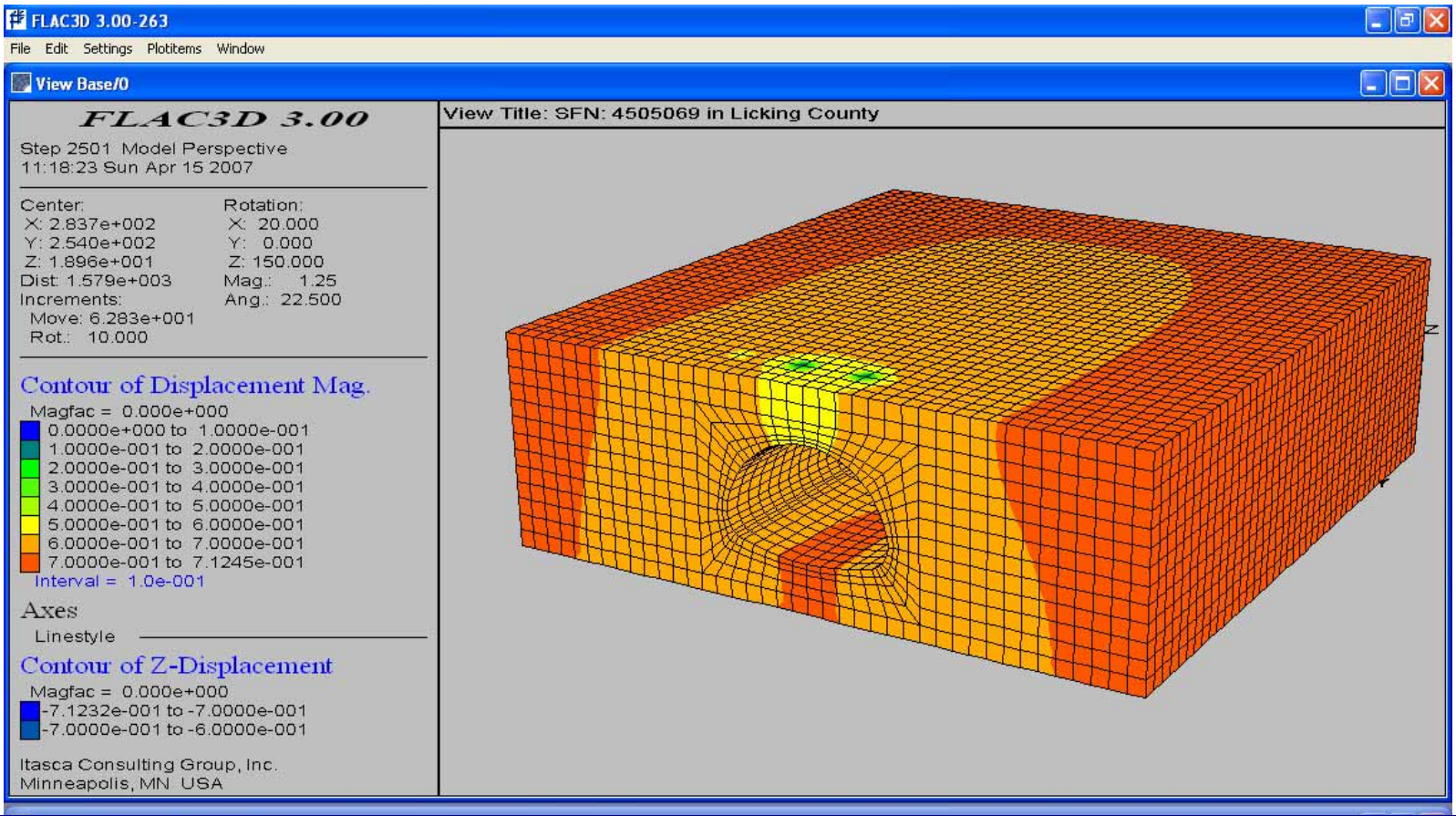
- Calculated deflections are much larger than measured deflections.
- Trend is similar.

FLAC-3D MODELING PROGRESS



- 3-Dimensional model
- Soil-structure interaction
- Static as well as dynamic analysis
- Nonlinear material behavior
- User defined material properties

PRELIMINARY RESULTS



- **Elastic analysis of LIC-79-2276**
- **Maximum calculated deflection = 3.16 mm**
- **Maximum measured deflection = 0.23 mm**

Evaluation of ODOT's CMP-Excel Program

- **Used for evaluation of corrugated steel culverts**
- **Provides a "Load rating (LR)" factor (smaller of):**
  - ***Rating Factor based on wall strength (RFW)***
  - ***Rating Factor based on minimum cover (RFC)***

➔**For shallow culverts, RFW does not affect LR because RFC is very small. Thus,**
- ***Material type does not matter***
- ***Magnitude of wall thrust does not matter***
- ***External loads do not matter***

➔**A better method is needed to evaluate the relation between RFW and RFC**

Current Work: Evaluation of CMP-Excel

Using test data, evaluate CMP-Excel:

- **Compare the culvert response with load rating factors:**
  - Use measured deflections, and moments and thrust forces calculated from measured strains

- **Evaluate the effectiveness and significance of each parameter in CMP-Excel:**
  - Rating Factor based on wall thrust
  - Rating Factor based on minimum cover

SUMMARY

Experimental Research:

- 38 culverts have been tested
- Test data and critical parameters have been evaluated

Analytical Research:

- CANDE: Modeling and analysis completed
- FLAC: Modeling and preliminary analysis completed
- CMP-Excel: A better method is needed

CONCLUSIONS

Experimental Research:

- **Culvert deflections decrease nonlinearly with increasing soil backfill height**
- **Maximum deflections are close to zero for deep culverts (backfill height > 13 ft or 4 m)**
- **Substantial increase in strains and deflections in shallow culverts (backfill height $\leq$ 8 ft or 2.5 m))**
- **It is difficult to predict the deflections in shallow culverts (age, soil type, condition may be as important as backfill and loading)**
- **Maximum dynamic deflections are 10-30% less than maximum static deflections**

CONCLUSIONS

Analytical Research:

- **CANDE: Predicted deflections are too large**
- **FLAC: More analyses with refined models are needed**
- **CMP-Excel: Better/simplified methods are needed**

THANK YOU

- **QUESTIONS?**
- **COMMENTS?**

Load rating factor in CMP-Excel

Operating Load Rating Factor

a. Rating factor based on wall strength

$$RFW = \frac{T_{cap} - 1.95T_E}{1.3T_{L+i}}$$

where,

T_{cap} = **thrust capacity of the wall**

T_E = **pipe wall thrust due to earth cover**

T_{L+i} = **pipe wall thrust due to live load plus impact**

b. Rating factor based on minimum cover requirement

$$RFC = \frac{H^2}{C \cdot h^2}$$

where,

H = **backfill height**

h = **the AASHTO minimum cover**

C = $2.36H/s + 0.528 \leq 1.0$

s = **span length**