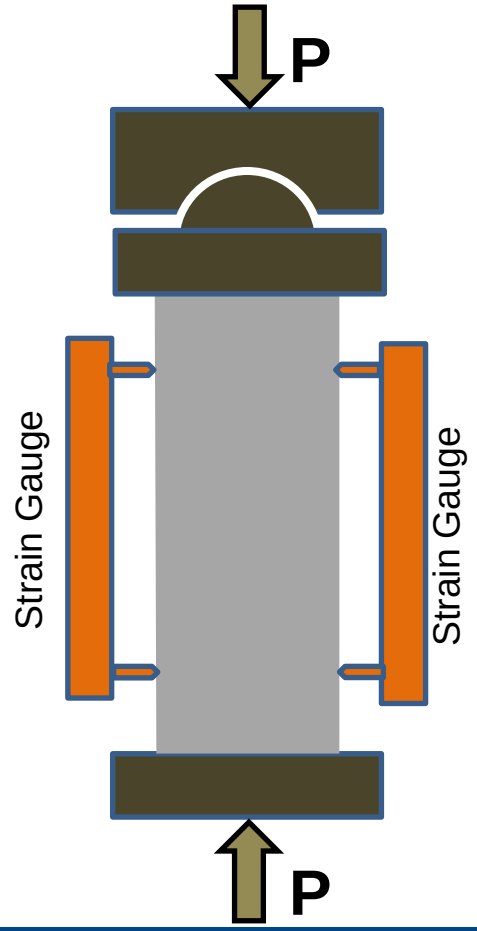
Compressive fatigue testing a new approach



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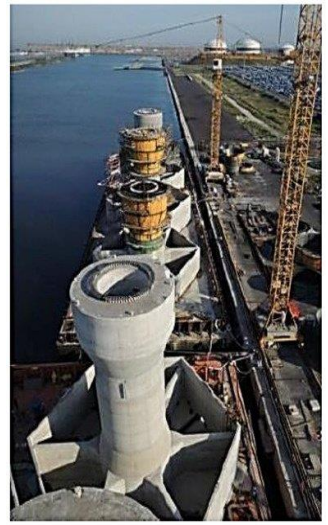


Outlines:

- Introduction of the project
- Use of concrete in offshore and onshore wind turbine structures and foundations
- Brief introduction of fatigue testing / loading
- Data base and the variation in results (effect of concrete strength)
- Recommended Protocol for Compression Fatigue Testing of Concrete
- Future Work

Introduction to the Project:

EFFECT OF FATIGUE ON THE CAPACITY AND PERFORMANCE OF STRUCTURAL CONCRETE

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

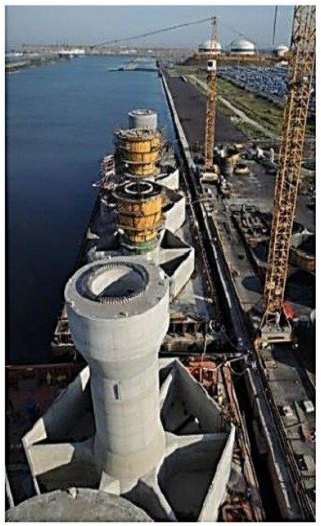
Stated Project Goal

This project's primary goal is to advance innovation in concrete offshore wind support structures (i.e. towers and foundations) by an experimental study that quantifies the effect of fatigue on the strength, stiffness, and durability of marine concretes, and then uses this data to advance models and standards. Currently, the impact of fatigue on structural concrete in standards is treated the same for all concretes regardless of the type of concrete material, and it neglects the benefits of fibers, bar reinforcements, and other effects. This one fatigue model can be conservative by more than a factor of 10 which leaves existing capacity on the table, and does not support simple design solutions that enable higher fatigue stresses to be tolerated. This is a major barrier to the competitiveness of concrete solutions. The new data, models, and standards that this project can deliver will give designers and developers the tools they need to drive innovation, reduce costs, and produce more resilient concrete Offshore Wind Support Structures (OWSS).

Selected Concrete Support Structures for Wind Turbines

Onshore wind turbine concrete towers

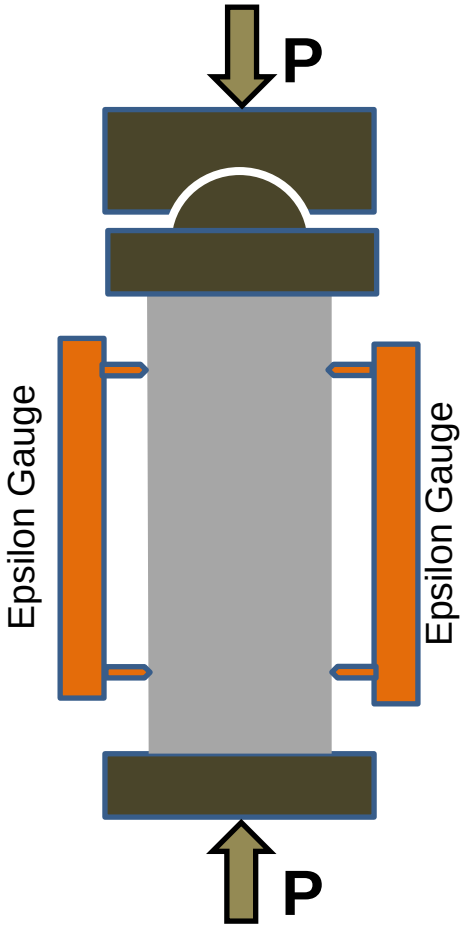
Offshore wind turbine concrete fixed base foundations



Offshore wind turbine floating foundations

Concrete anchors for floating Offshore wind turbines

Response of concrete material to static and cyclic loading



f'c = strength of concrete

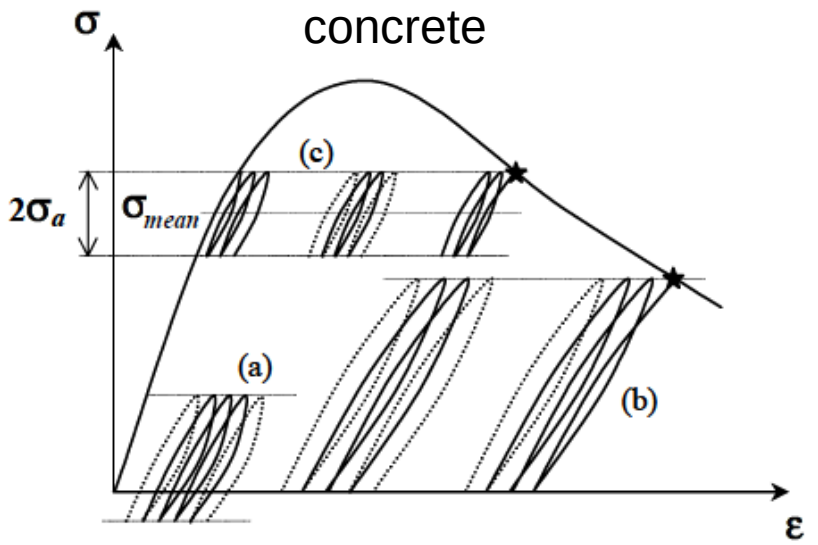


Figure 5.2. *Behavior of concrete under cyclic loading: a) alternate loading; b) repeated loading; c) undulated loading*

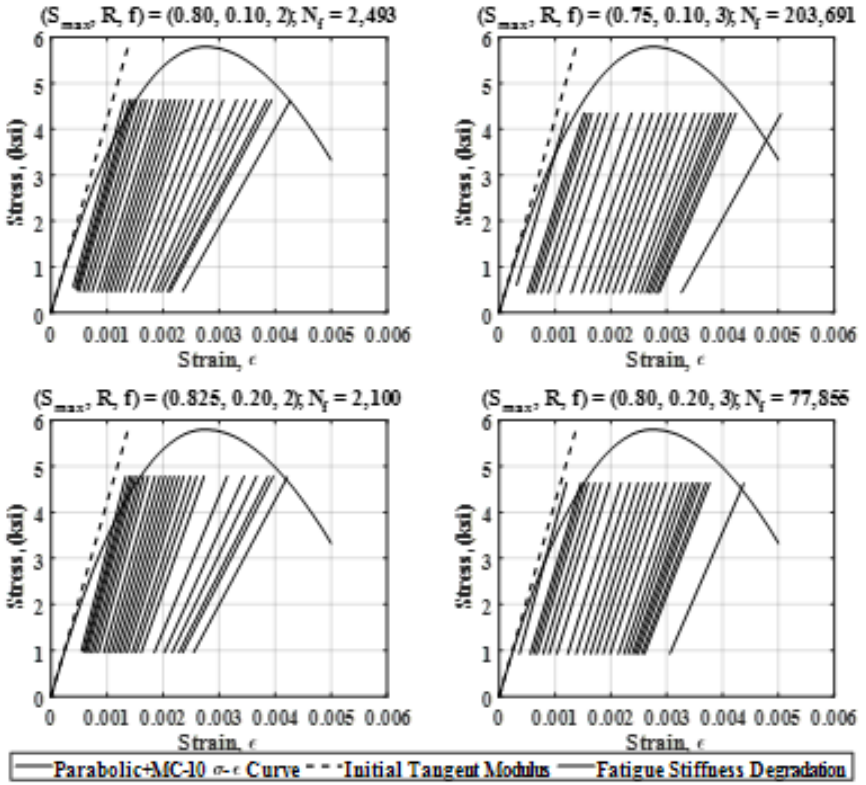
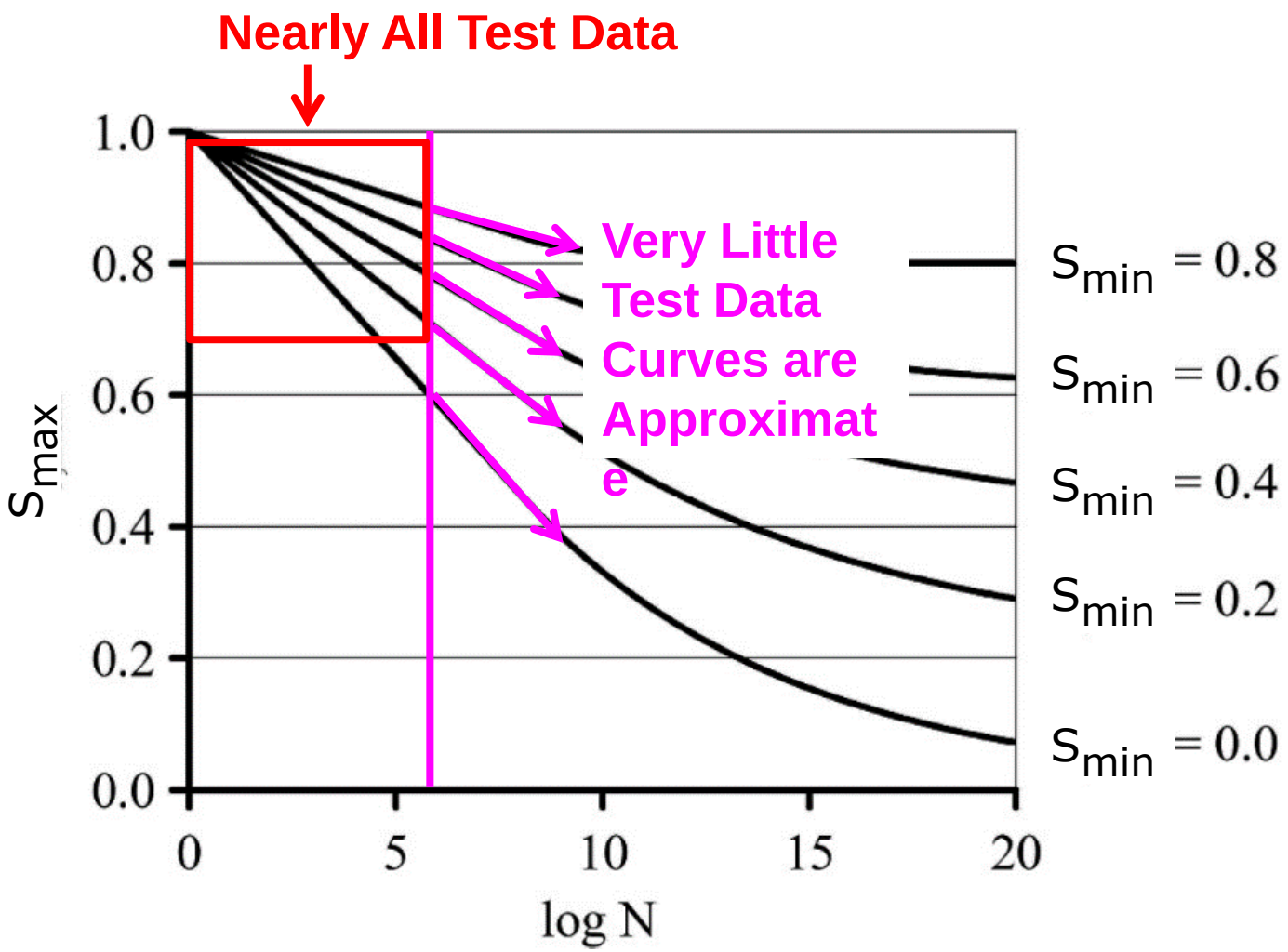


Figure 12: Secant stiffness degradation under fatigue loading for different (S_{max}, R, f) combinations, along with relationship of stiffness degradation to failure (1ksi = 6.89 MPa)

ASTM C39 Monotonic testing
Loading rate 35±7 psi/sec

(Viswanath et al., 2021)

Concrete Fatigue (S-N) Models (Model Code 2010)



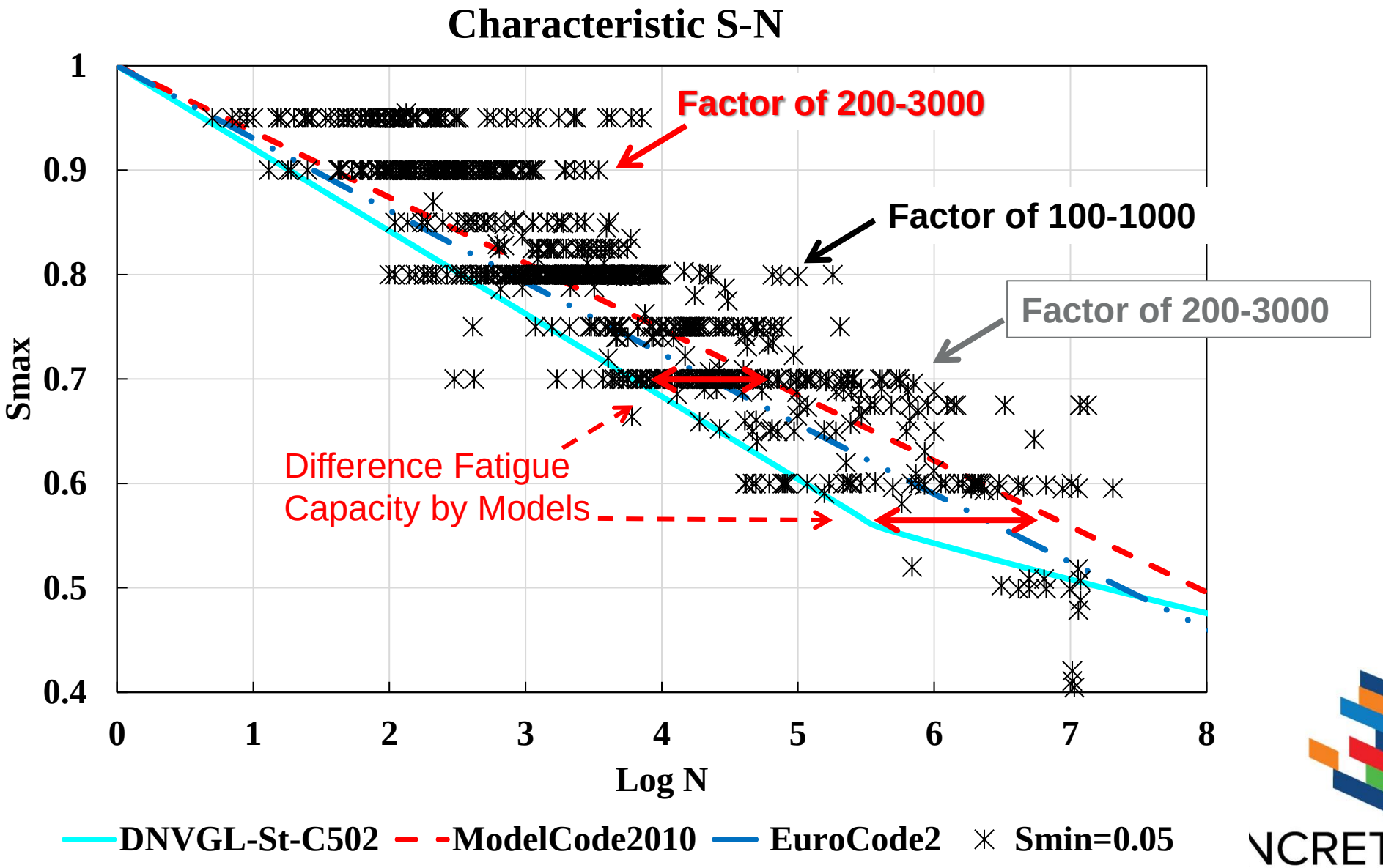
fib Model Code Fatigue Curves

$$S_{max} = \frac{\text{(Max. Applied Stress in Cycle)}}{\text{(Monotonic Stress Capacity)}}$$

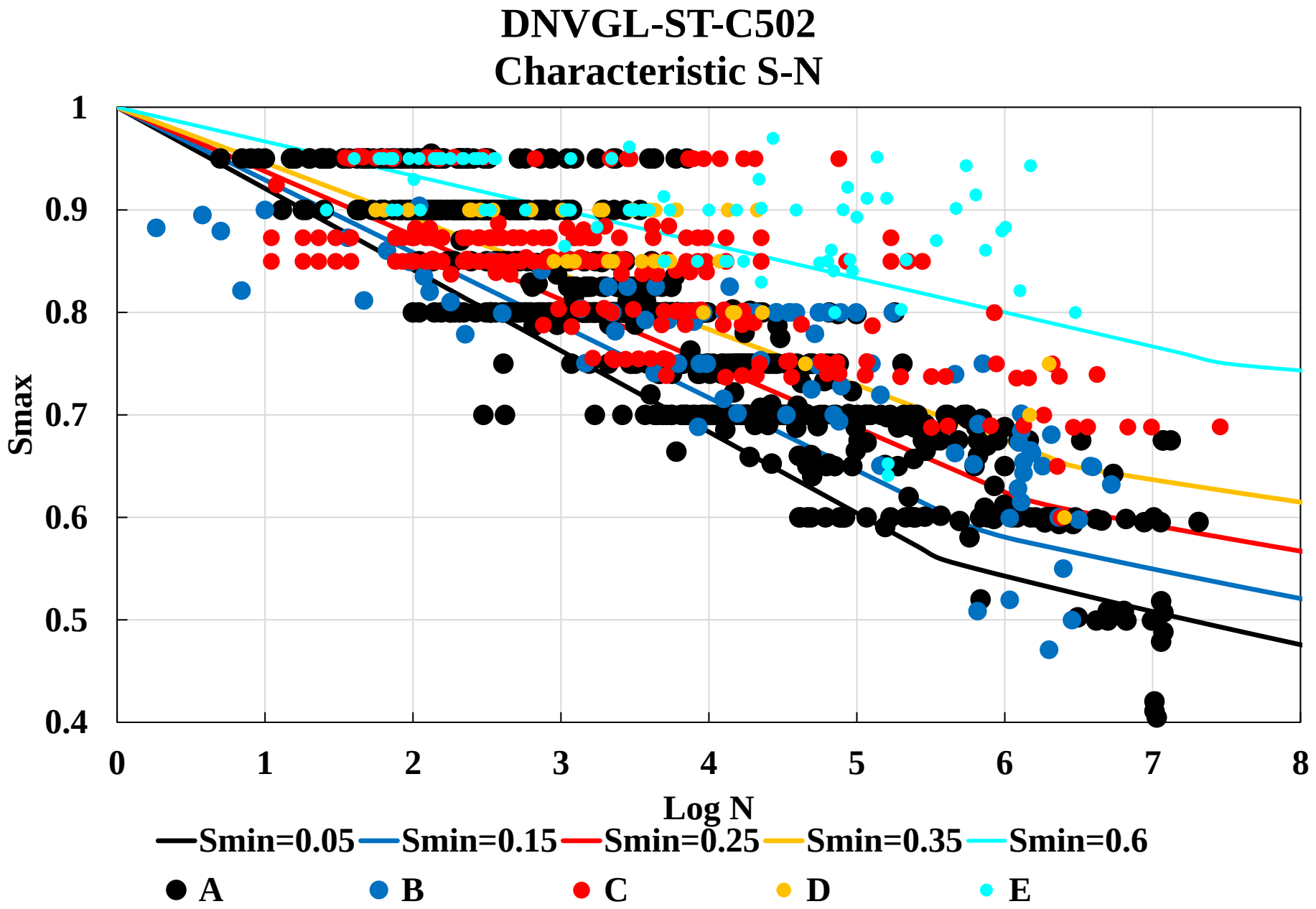
$$S_{min} = \frac{\text{(Min. Applied Stress in Cycle)}}{\text{(Monotonic Stress Capacity)}}$$

Concrete Fatigue (S-N) Models and Data Base

Smax=
σmax/strength



Concrete Fatigue (S-N) Models and Data Base



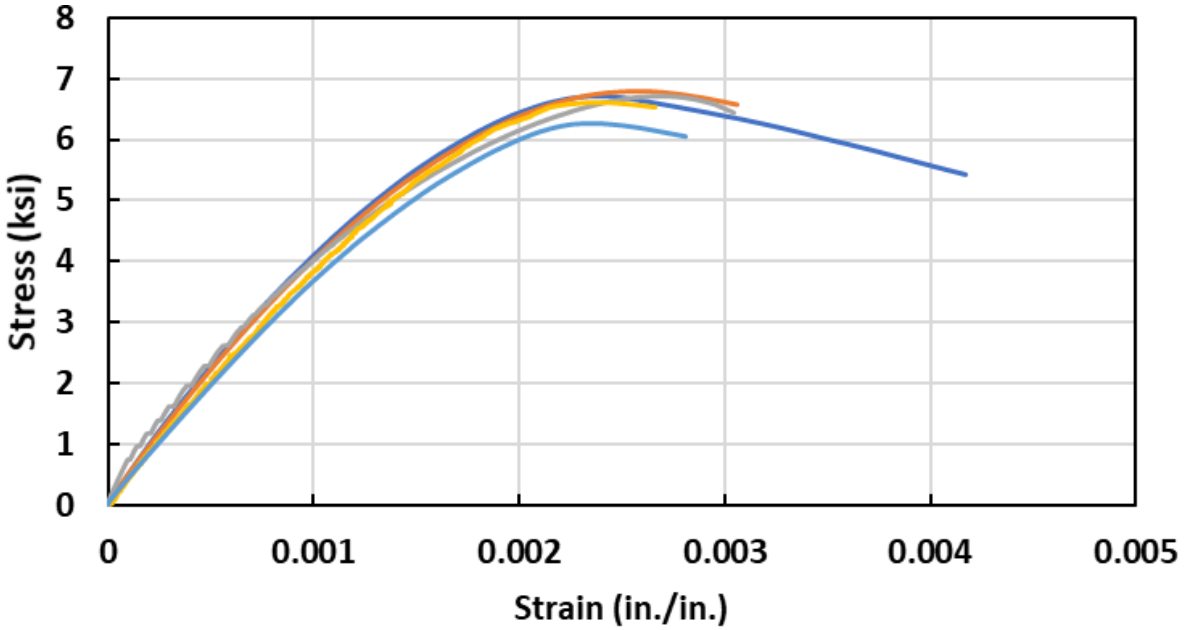
Recommended Protocol for Compression Fatigue Testing of Concrete

Tech Note for ACI fatigue Committee 215

Effect of variation in strength of concrete

Monotonic compressive stress-strain curves

Coefficient of variation = 2%

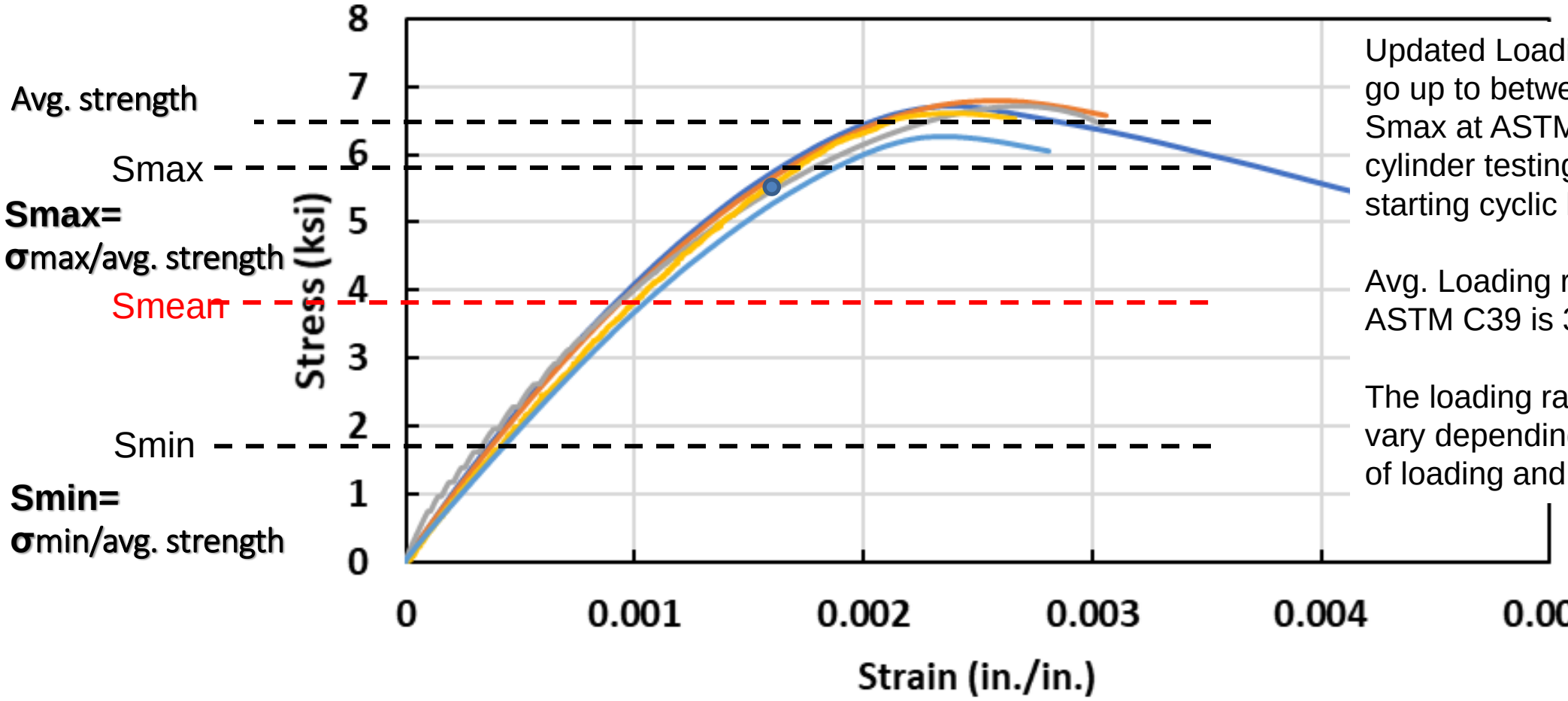


Example 1 Example 2

fcm	Smax	Smin	Number of cycles to failure (Nf)		
			Model Code 2010	DNV	Eurocode
fcm-5% (If strength was 5% lower)	0.84	0.21	1,797	269	386
fcm (Planned Smax=0.80)	0.80	0.20	10,208	1,000	1,711
fcm+5% (If strength was 5% higher)	0.76	0.19	54,996	3,594	7,582
fcm-5% (If strength was 5% lower)	0.63	0.21	33,572,059	417,112	2,208,912
fcm (Planned Smax=0.60)	0.60	0.20	104,199,038	1,000,000	7,220,567
fcm+5% (If strength was 5% higher)	0.57	0.19	322,815,611	2,805,597	23,602,833

New method for compressive fatigue testing

Guesstimating strength of concrete (f'c)



Updated Loading Protocol is to go up to between Smean and Smax at ASTM C39 specified cylinder testing rate before starting cyclic loading

Avg. Loading rate based on ASTM C39 is 35±7 psi/sec

The loading rate for fatigue vary depending on frequency of loading and loading range.

New method for compressive fatigue testing

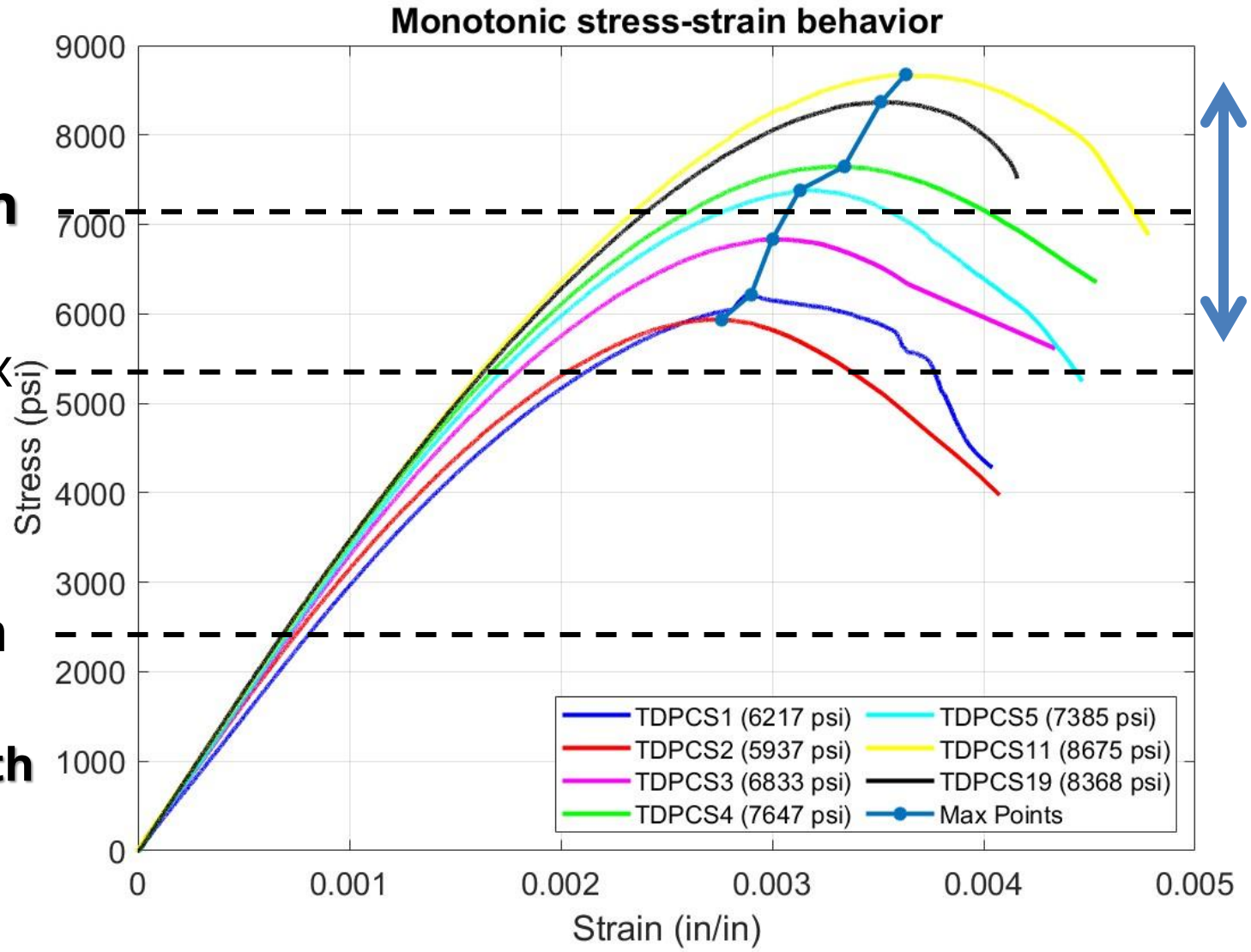
Avg. strength

Smax

Smax=
σmax/avg. strength

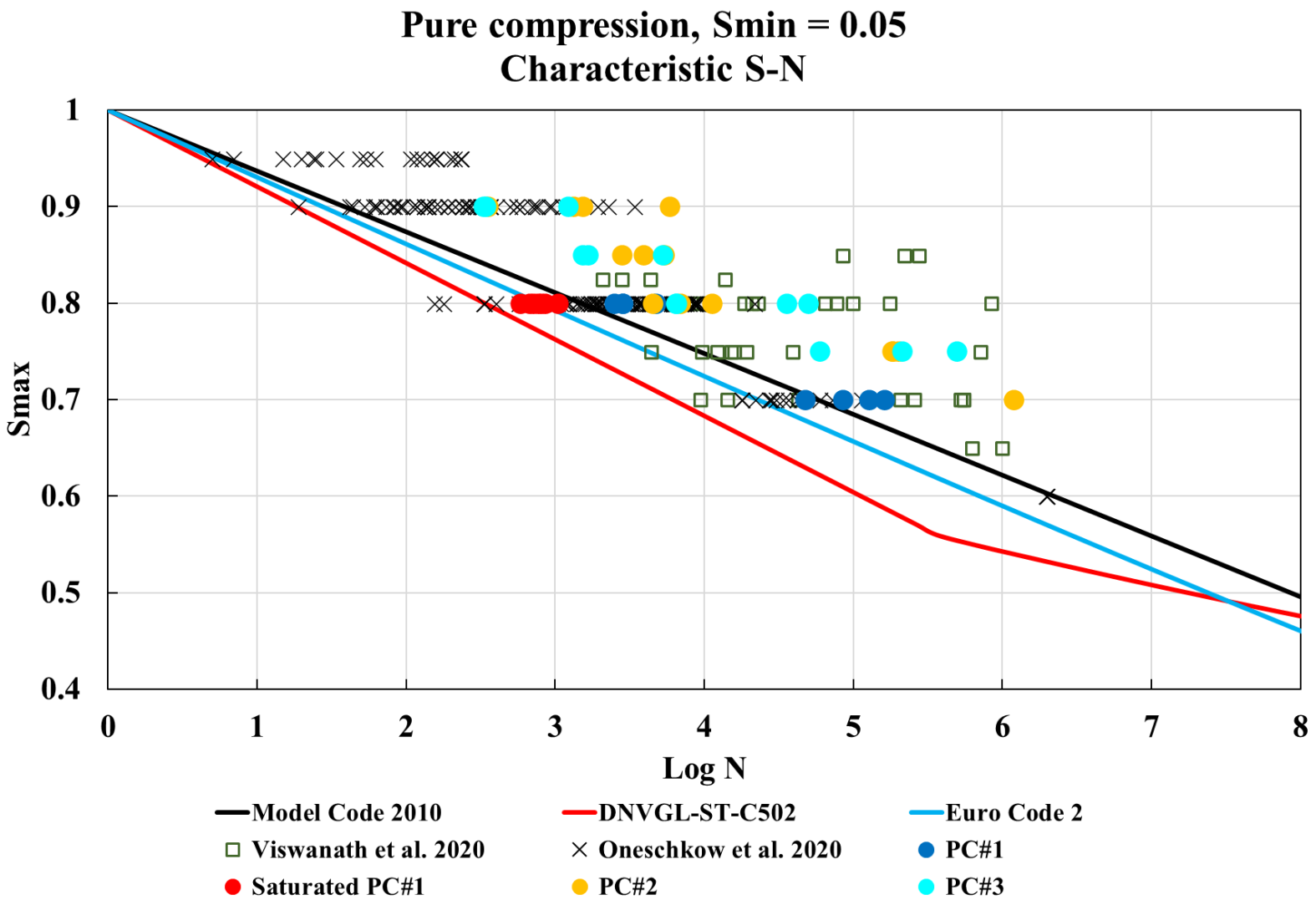
Smin

Smin=
σmin/avg. strength



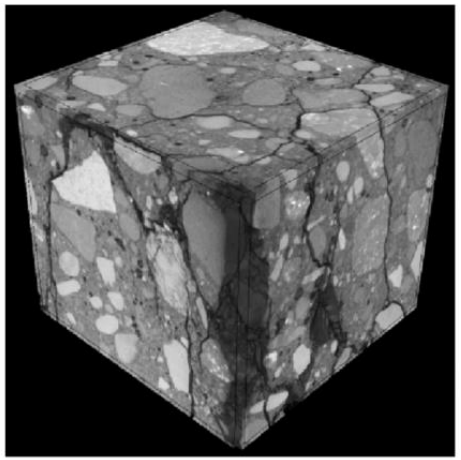
~30% variation

Effect of the new method on the recent test results



Continued experiments and works:

- Ongoing testing with 3 different types of concrete to verify usefulness of suggested methods (LWA concrete, Concrete with crushed granite aggregate, concrete with river based round aggregate)



- X-Ray Microtomography (aka computed tomography) on couple of concrete specimens to explore possible link between internal damage and the strain accumulation due to fatigue

Takeaways

- The suggested method of compressive fatigue testing considering the variation of concrete strength in defining the fatigue loading protocol will reduce the fatigue capacity testing results range

- Having a standardized method for defining fatigue capacity model (curve) will help to have a more optimized design of the structure

Thank you for your attention!

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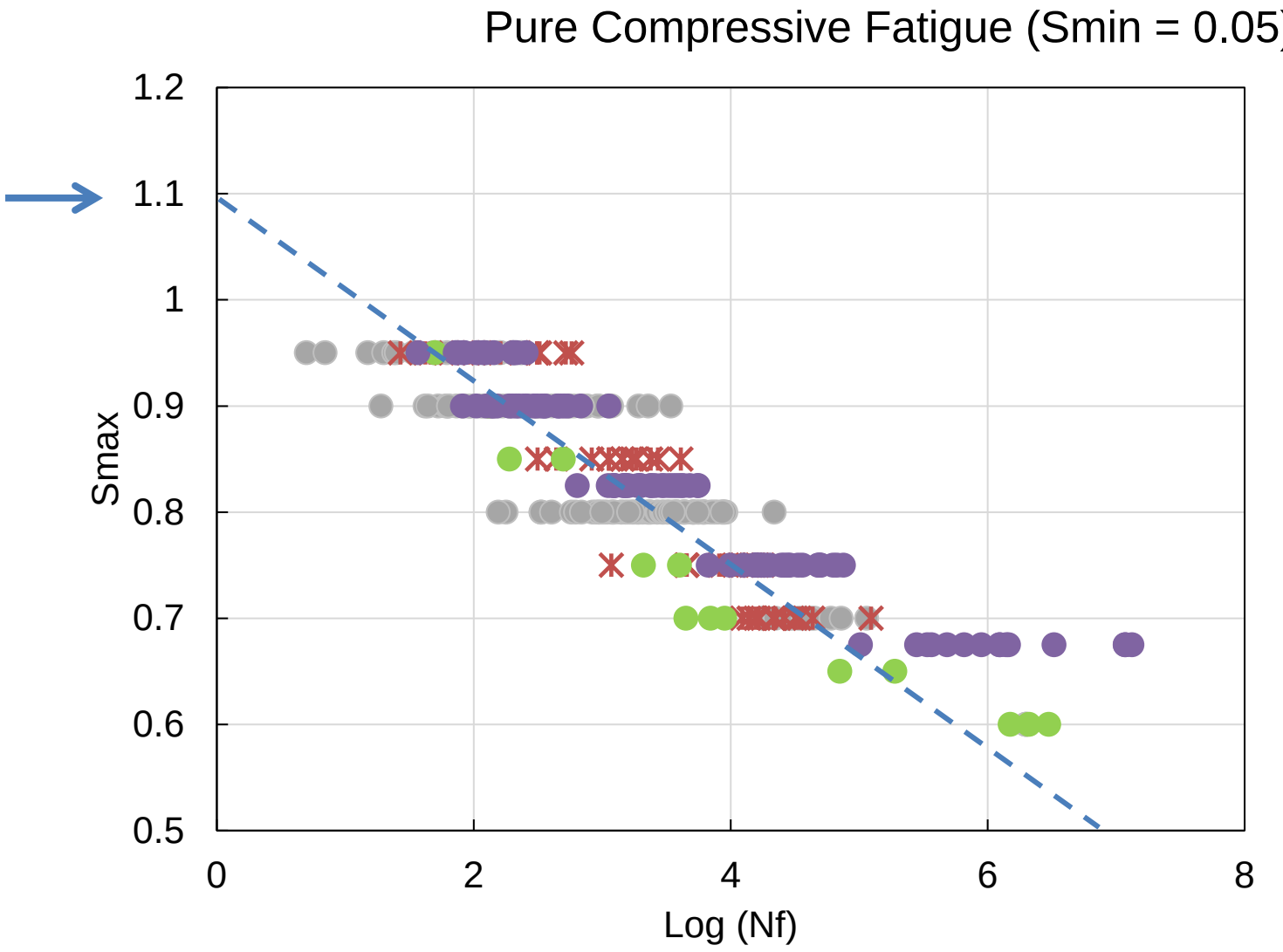
Tech Note #2

Procedure for Concrete Compression Fatigue S-N Curve Development (Certification by Testing)

Why we need a standard method for developing S-N Curve?

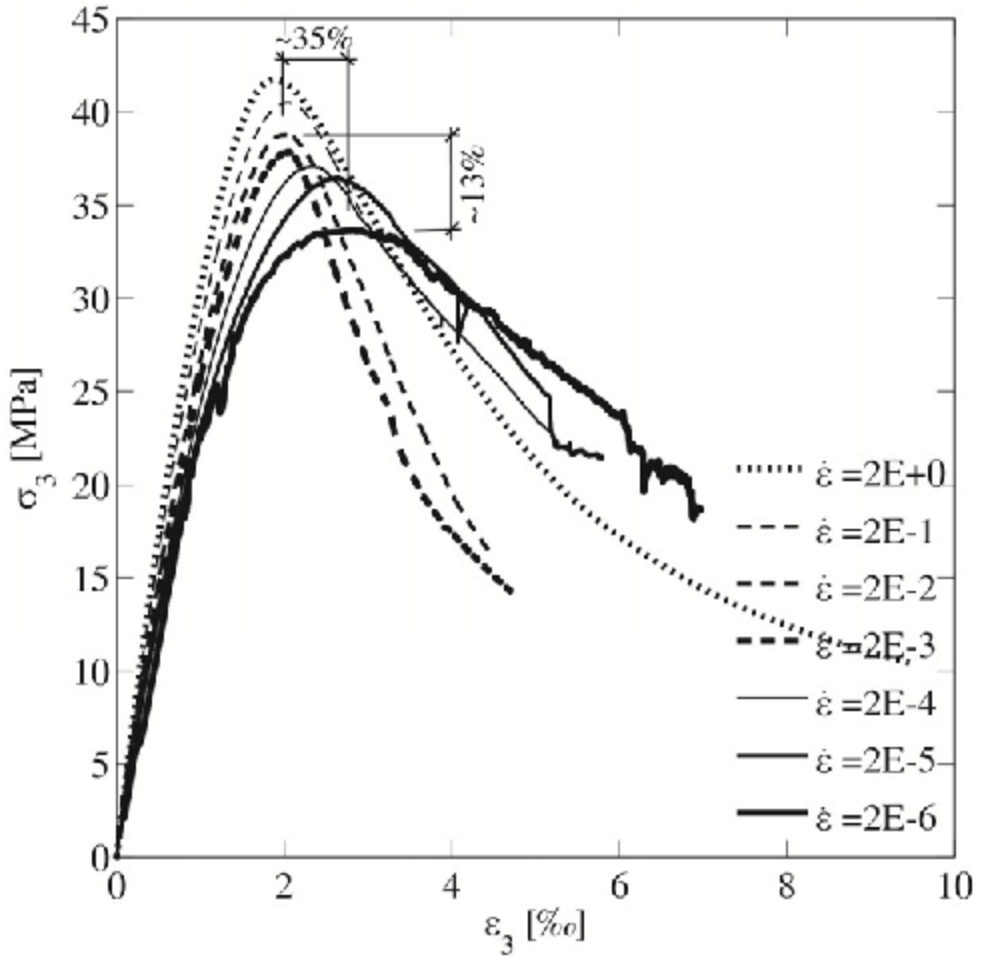


Standard monotonic test (ASTM C39) loading rate is equal to 35±7 psi/sec

Fatigue loading rate is 150-300 times faster than standard rate

- Oneschkow et al. 2020
- Do et al. 1993
- Petkovic et al. 1990
- Holmen 1979

Why we need a standard method for developing S-N Curve?

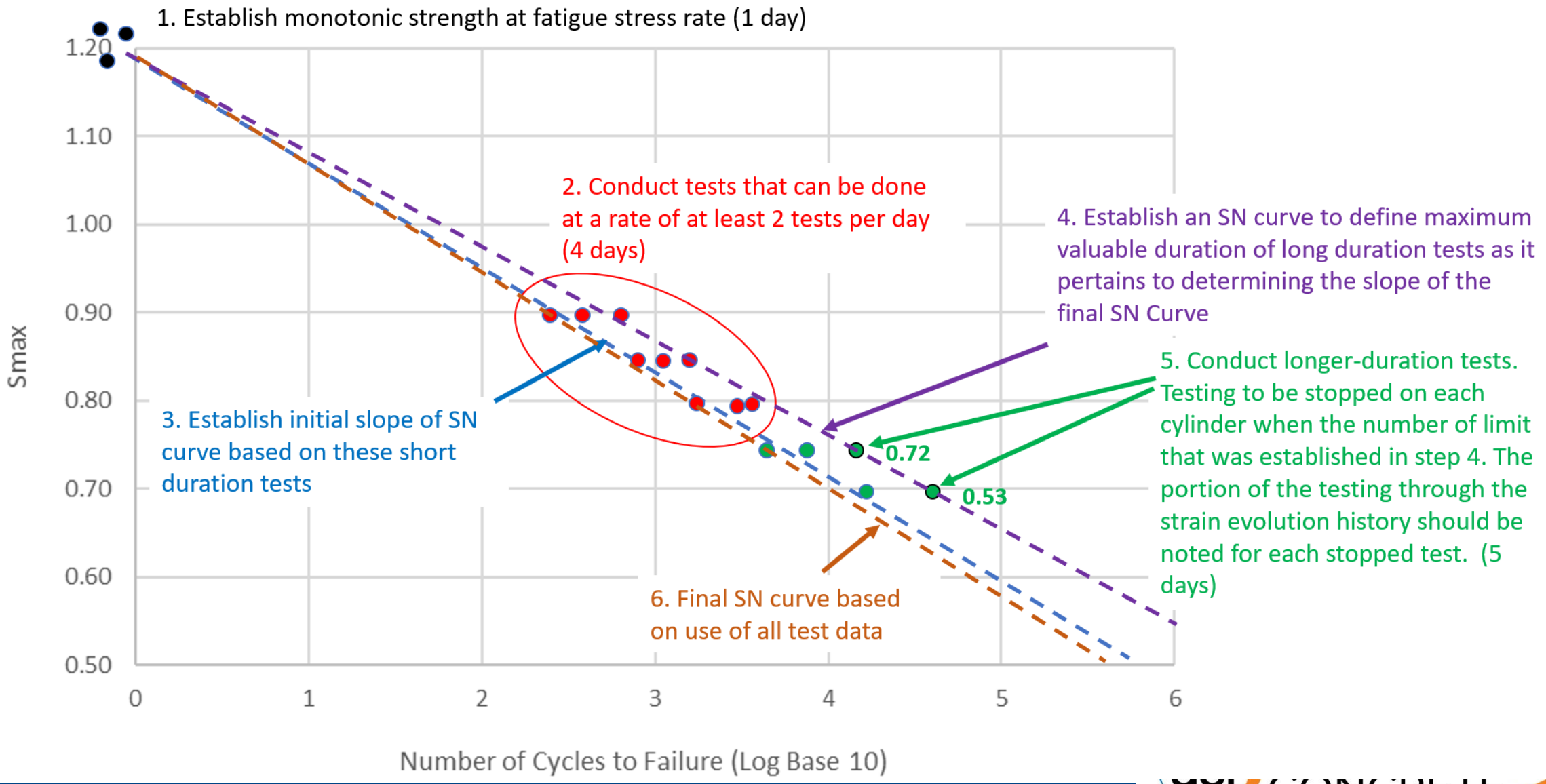


Standard monotonic test (ASTM C39) loading rate is equal to 35±7 psi/sec

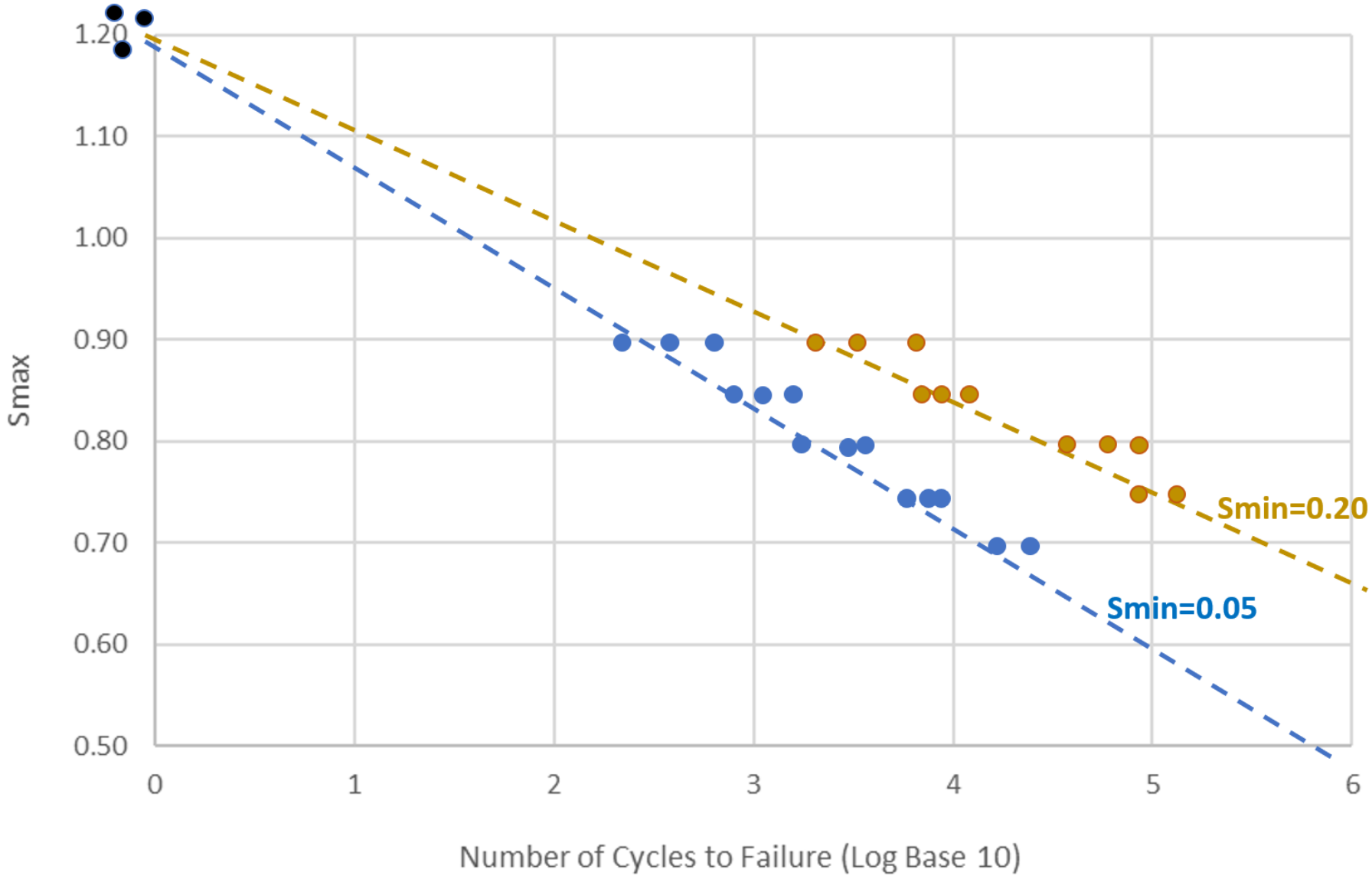
Fatigue loading rate is 150-300 times faster than standard rate

Higher rate of loading will result in higher strength

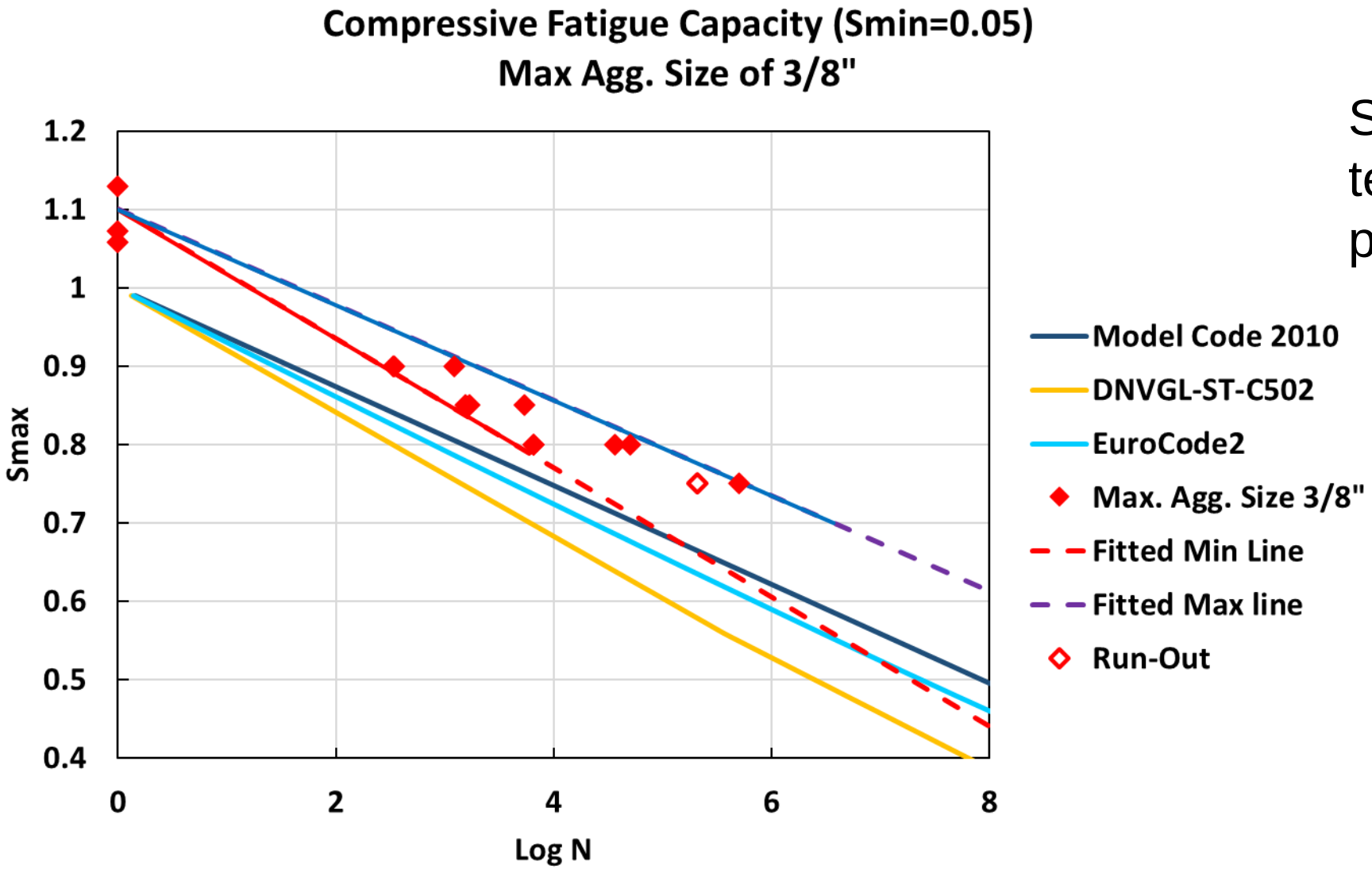
Procedure for Developing of a SN Curve



Procedure for Developing of a SN Curve



Example for Developing of a SN Curve



S-N data from current testing showing that this proposal is working