Using Genetic Algorithms in Design of Post-Tensioned Structures

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Outline

- The post-tensioning design problem
- Modern post-tensioning design approach
- Genetic algorithm fundamentals
- Application of genetic algorithm to the post-tensioning design problem
- Practical application to real world design

PT Design

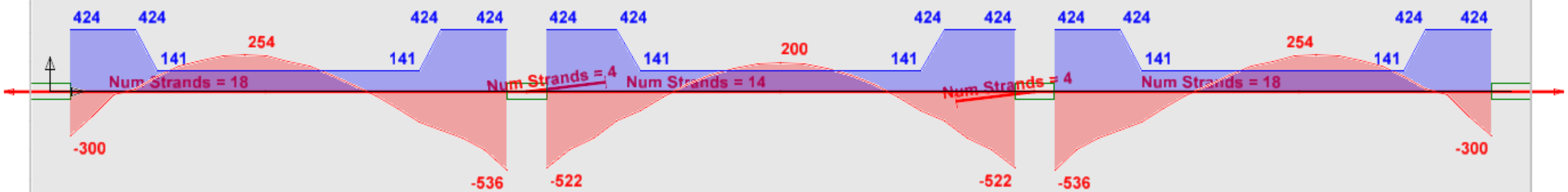
- Design Criteria
  - Strength (flexure, shear)
  - Serviceability (cracking, deflections)
  - Initial (transfer of prestress)
  - Minimum (precompression limits, minimum reinforcement)
- Understanding the suitability of a solution
  - Design Criteria Satisfied
  - Performance
  - Economics

PT Design

- Changes in one span/bay affect other regions
- Design parameters are interdependent
- Virtually infinite number of valid designs
  - Combinations of PT quantity, PT profiles, rebar quantity, studded shear reinforcement, etc.
  - Different tendon layouts in irregular slabs
  - Member thickness too!
  - Finding a valid design is often time consuming

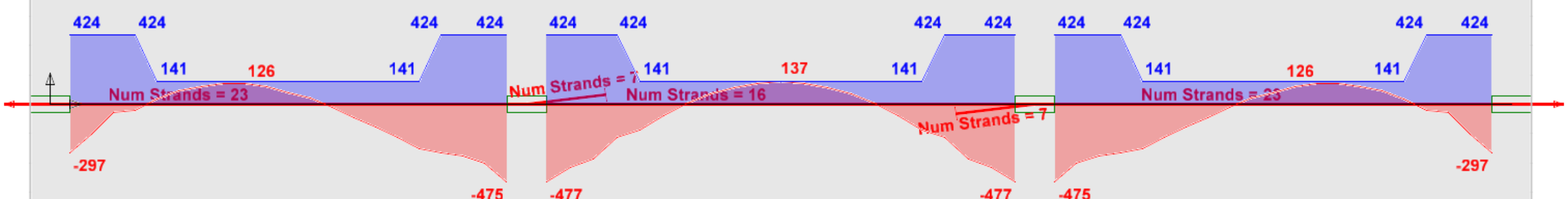
PT Design

Total reinforcement cost = 2990



PT Cost: 1260 Rebar Cost: 794 SSR Cost: 936

Total reinforcement cost = 2755



PT Cost: 1577 Rebar Cost: 302 SSR Cost: 876

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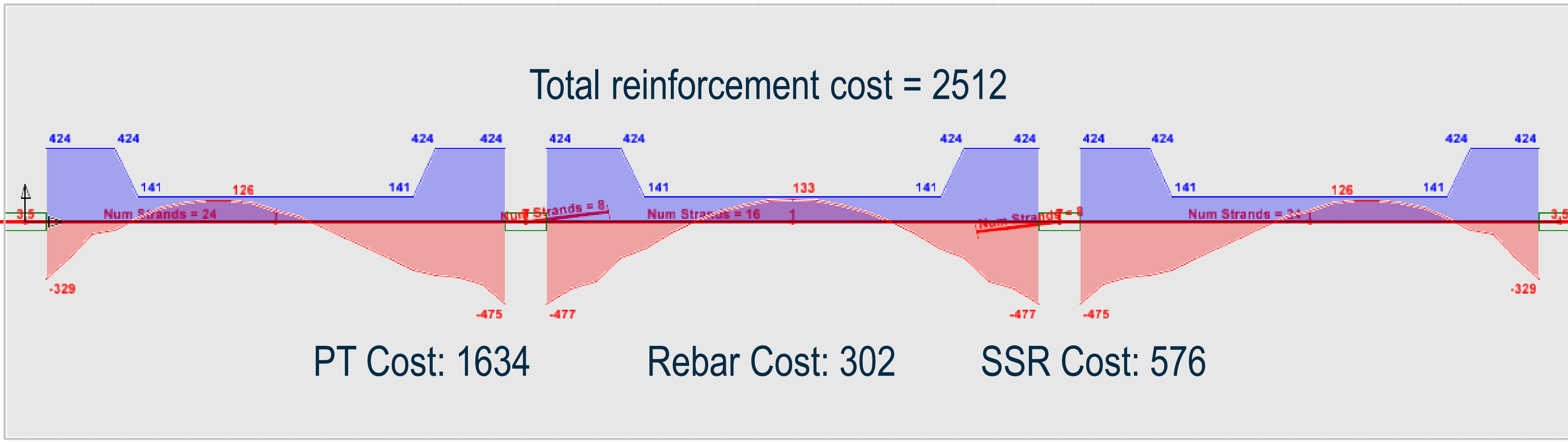
Modern Approach to PT Design

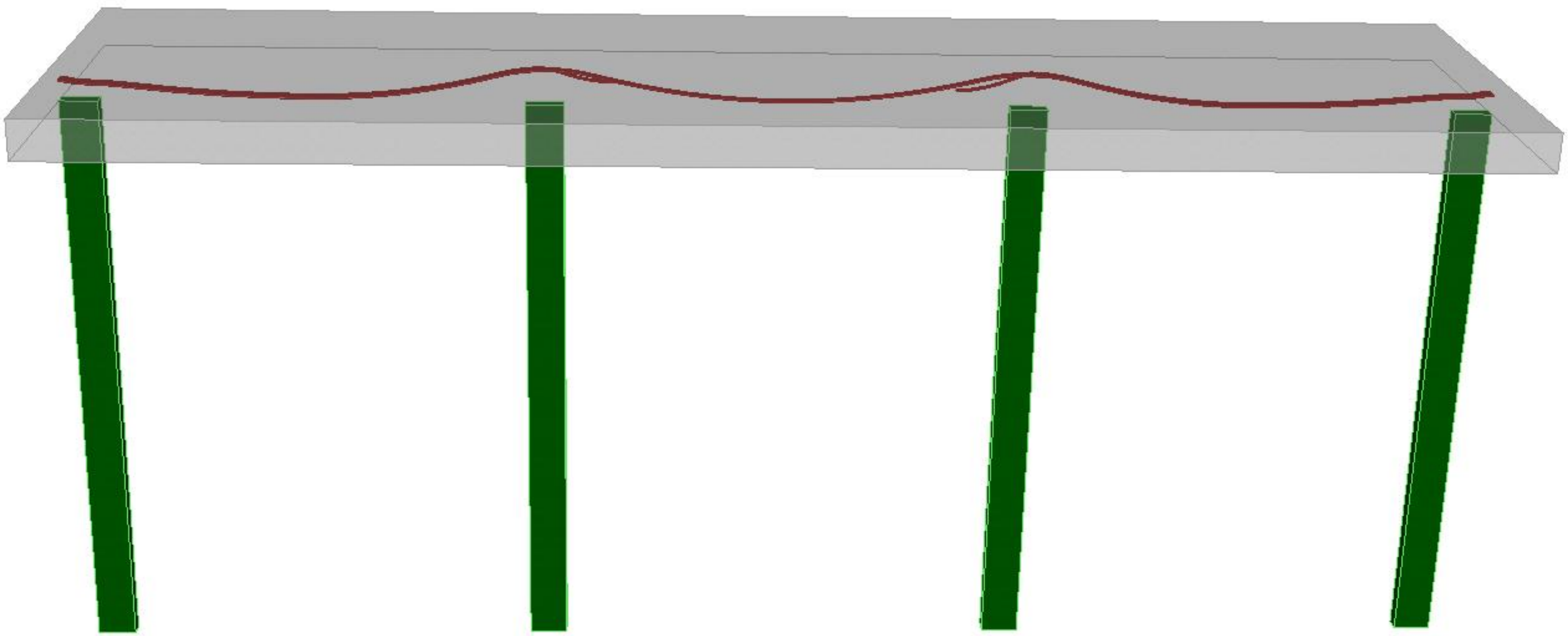
1. Select slab thickness based upon span/depth ratio
2. Provide post-tensioning to satisfy minimum provisions
3. Add post-tensioning to satisfy flexural tensile stresses
4. Design supplemental rebar required
5. Design for punching shear
6. Check service criteria (deflection, etc.)
7. Iterate as required

PT Design



- More PT
- Less Rebar and SSR
- End CGS slightly away from mid-depth
- Cost savings of 9%

What if?



Tendon Strands Span 1: 12-40

Tendon Profiles Span 1: 1”-4”

Tendon Strands Span 2: 12-40

Tendon Profiles Span 2: 1”-4”

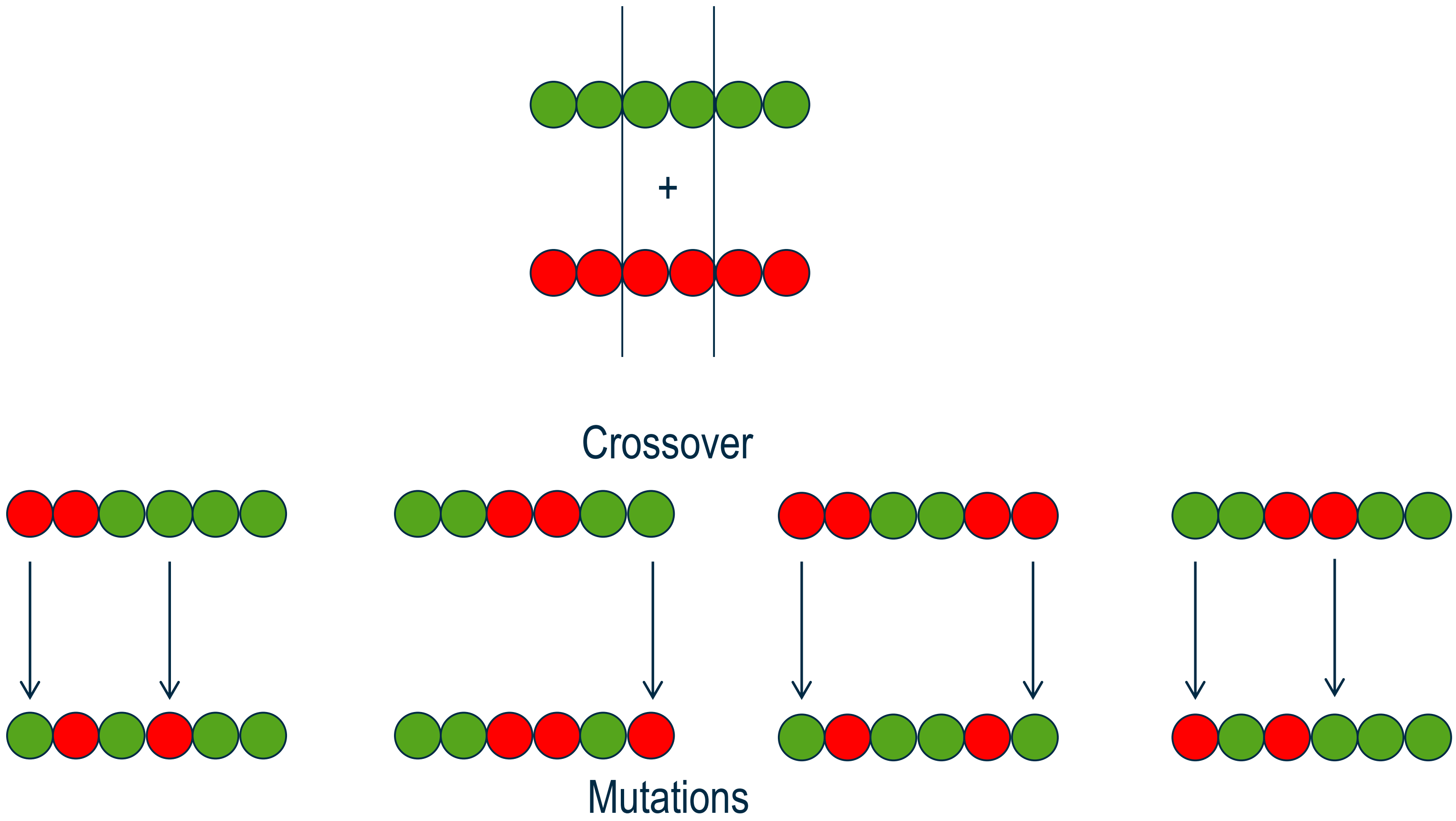
Tendon Strands Span 3: 12-40

Tendon Profiles Span 3: 1”-4”

Use 1 strand increments, ½” profile increments, vary end CGS between 3-5”

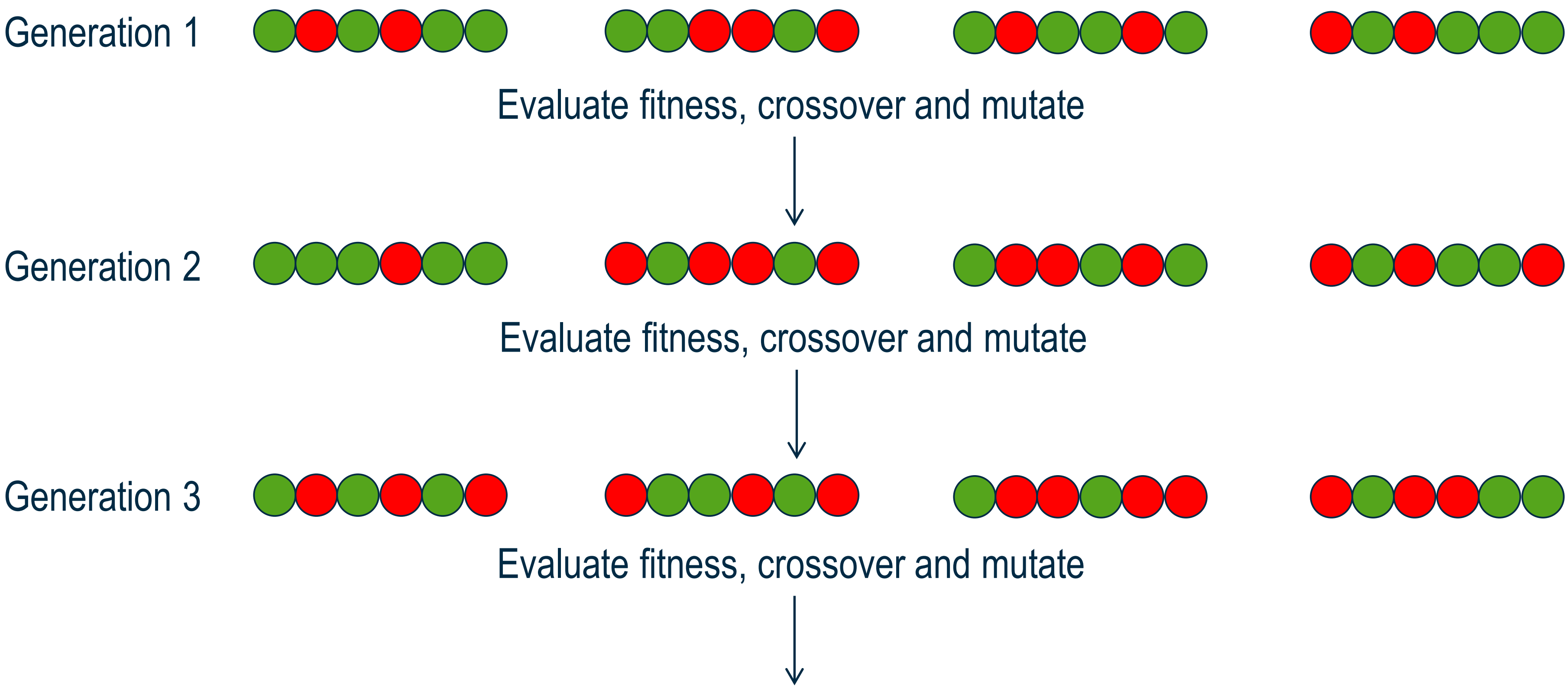
209,135,675 permutations !

Genetic Algorithm



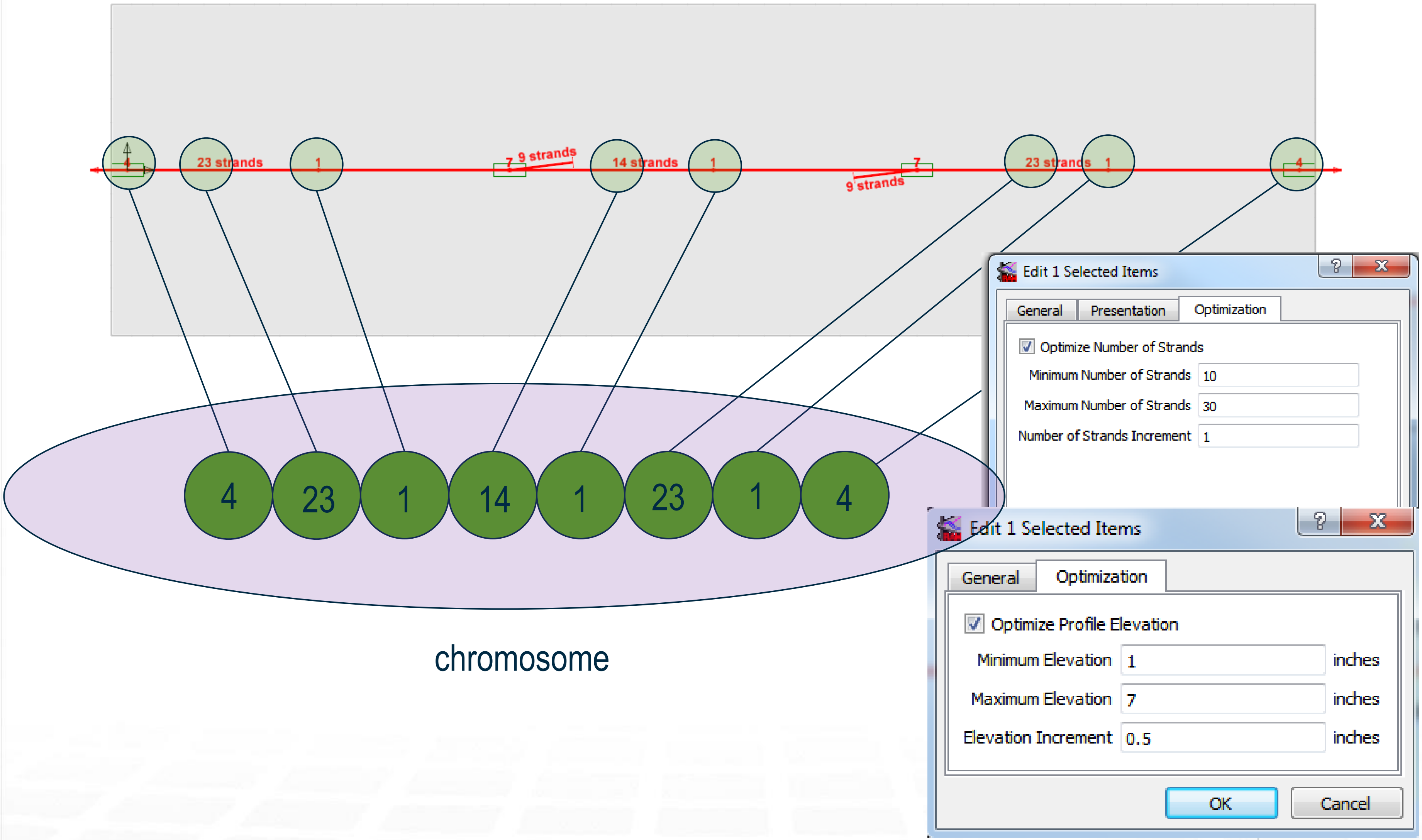
- Fitness value calculated for each chromosome used to determine the suitability of each
- Fittest in each population crossed to create next generation

Genetic Algorithm



Repeat until fitness value converges…

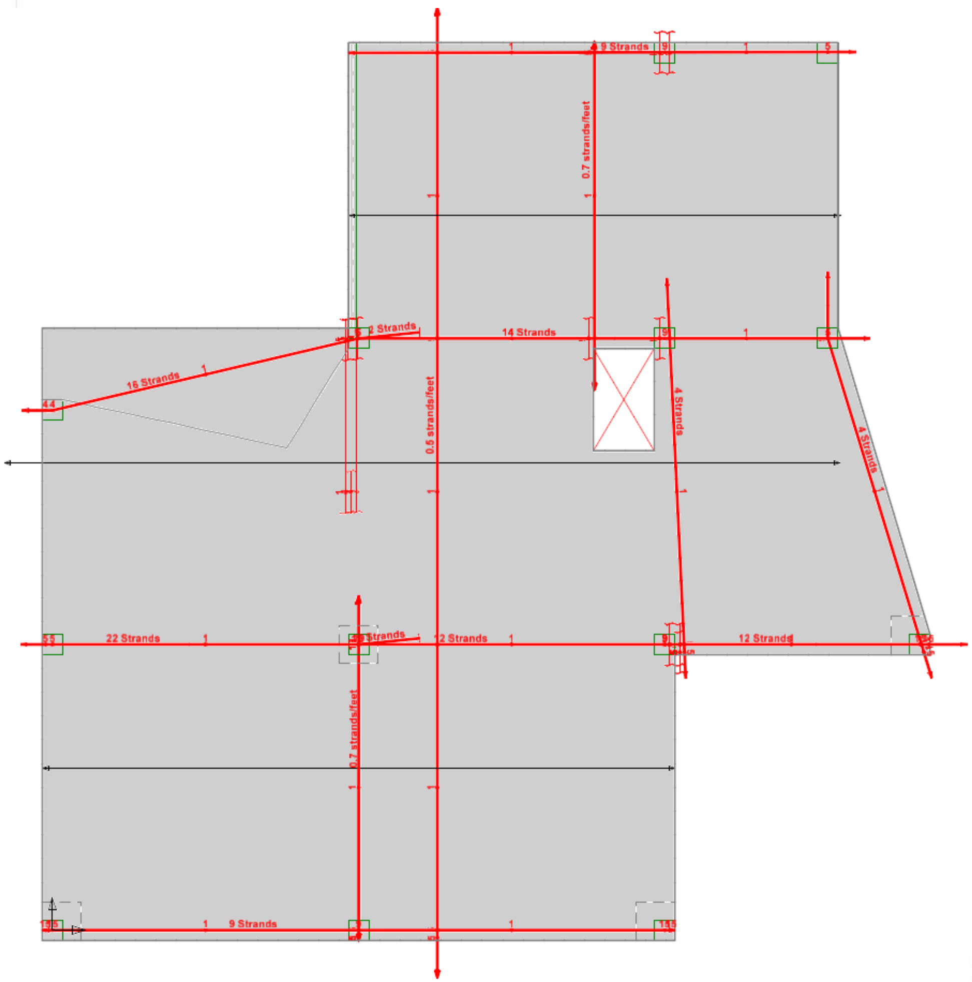
Application to PT Design

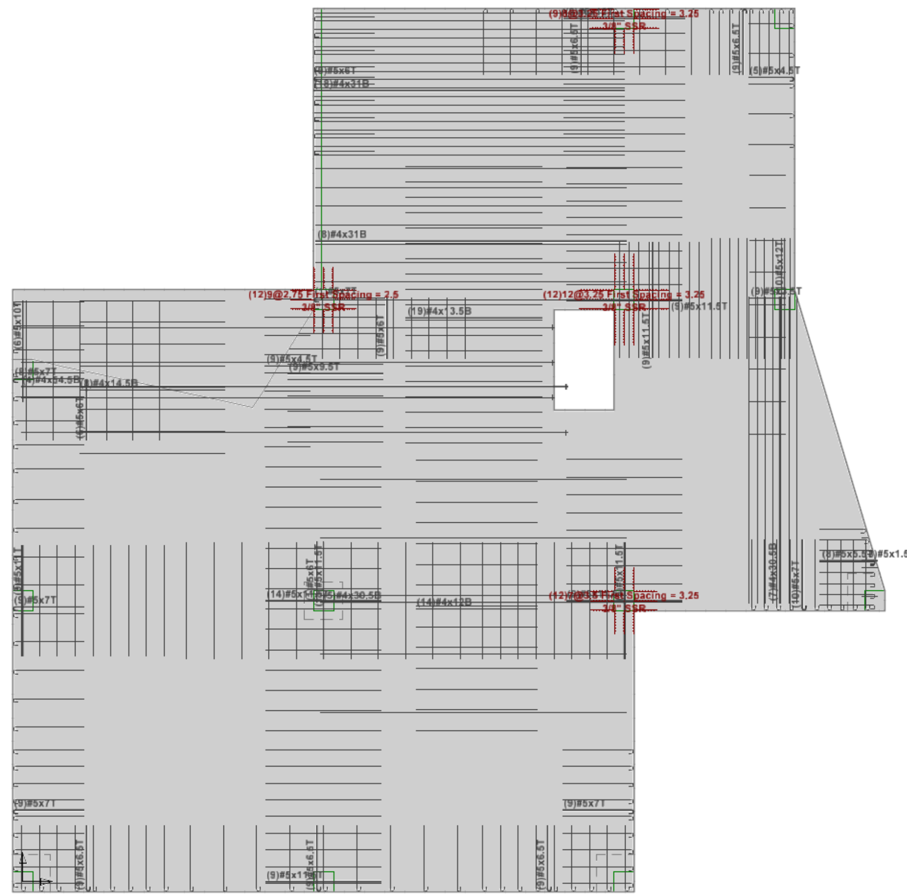


Application to PT Design

- Fitness value = PT cost + Rebar cost + SSR cost (materials and labor)
- Cost penalties can be added to discourage particular aspects of a solution
  - Failed cross section code check
  - Excessive deflection
- Other possibilities include:
  - Concrete/rebar material strength
  - Slab/beam member sizes
  - Tendon layout

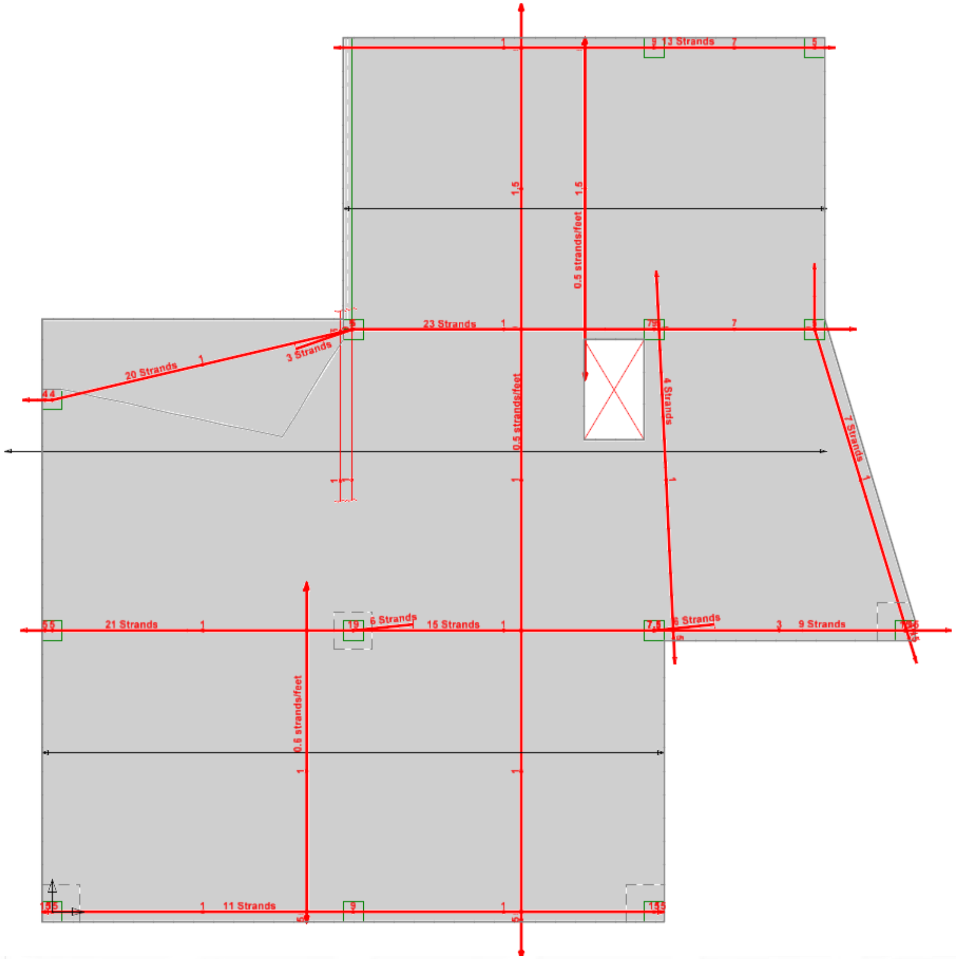
Application to PT Design

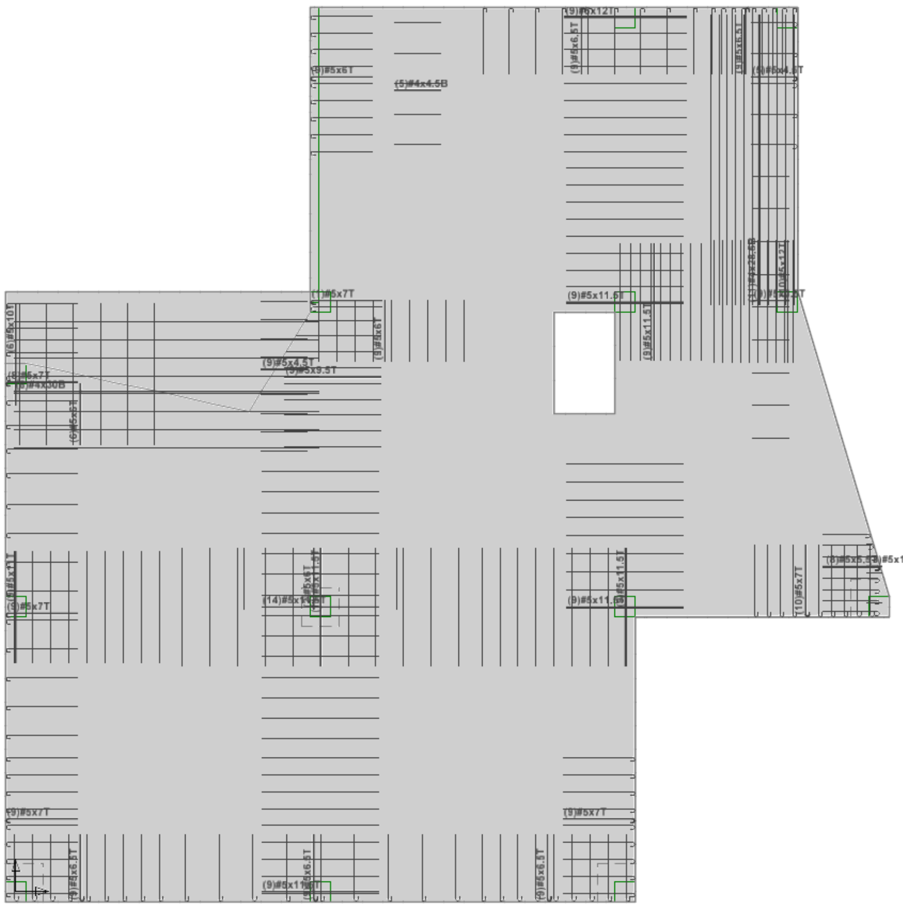




Manual Design

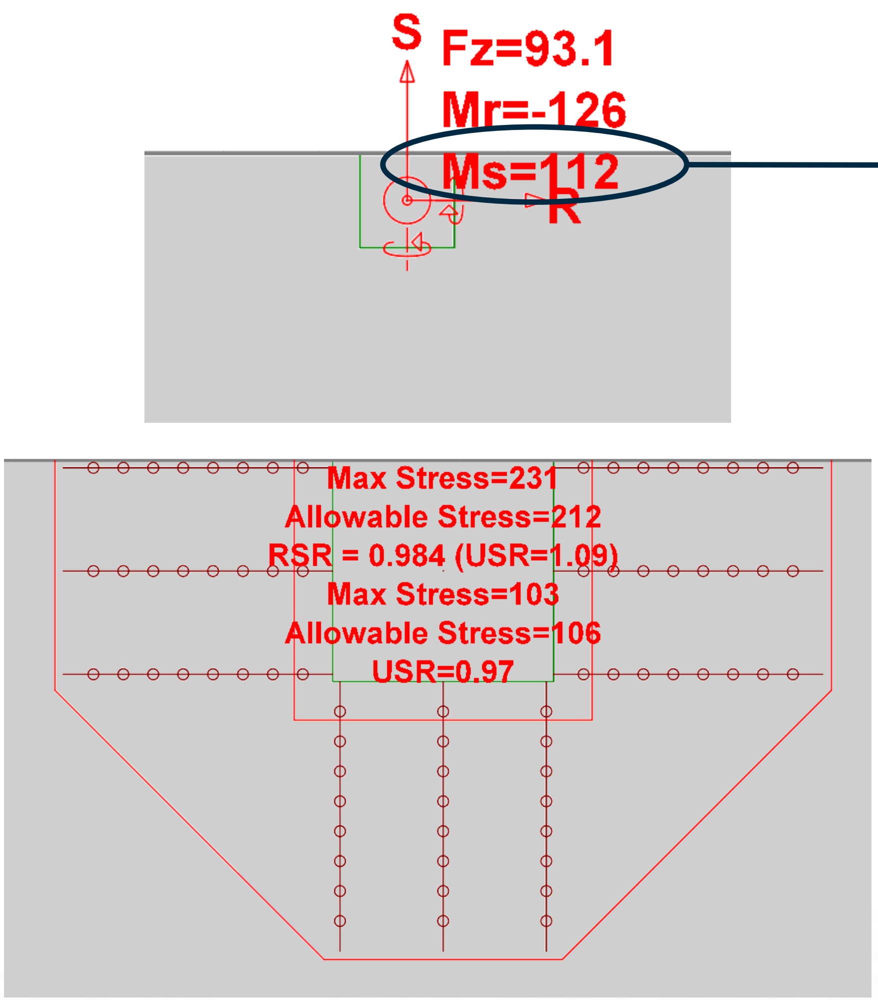
Application to PT Design



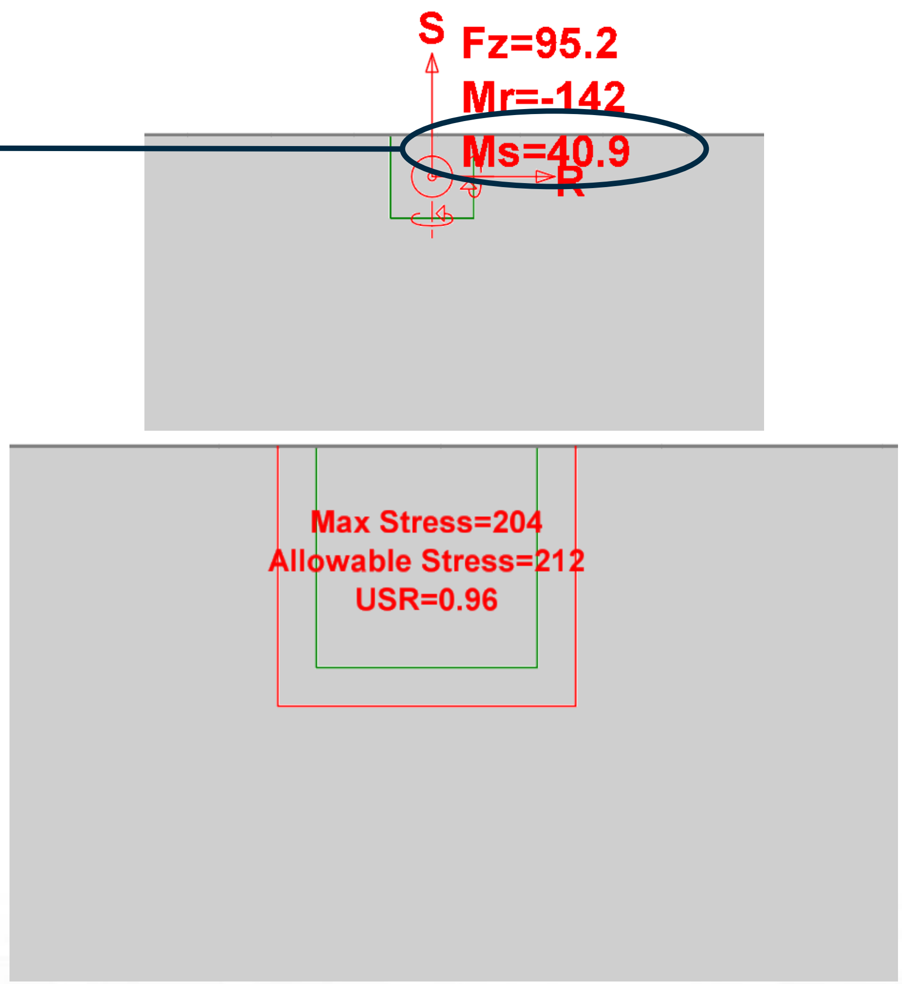


Optimized Design

Application to PT Design



Manual Design



Optimized Design

Application to PT Design

Concrete Costs								
Materials:	100	per	yd³	x	175.1	yd³	=	17510
Labor:	50	per	yd³	x	175.1	yd³	=	8754
Total:	150	per	yd³	x	175.1	yd³	=	26260
Post-Tensioning Costs								
Materials:	1	per	pounds	x	3845	pounds	=	3845
Labor:	0.5	per	pounds	x	3845	pounds	=	1923
Total:	1.5	per	pounds	x	3845	pounds	=	5768
Formwork Costs								
Materials:	1	per	ft²	x	5669	ft²	=	5669
Labor:	1	per	ft²	x	5669	ft²	=	5669
Total:	2	per	ft²	x	5669	ft²	=	11340
Mild Steel Reinforcing Costs								
Materials:	1000	per	tons	x	1.839	tons	=	1839
Labor:	500	per	tons	x	1.839	tons	=	919.3
Total:	1500	per	tons	x	1.839	tons	=	2758
SSR Costs								
Materials:	2	per	stud	x	408	studs	=	816
Labor:	1	per	stud	x	408	studs	=	408
Total:	3	per	stud	x	408	studs	=	1224
Total Costs								
Materials:	5.235	per	ft²	x	5669	ft²	=	29680
Labor:	3.117	per	ft²	x	5669	ft²	=	17670
Total:	8.352	per	ft²	x	5669	ft²	=	47350

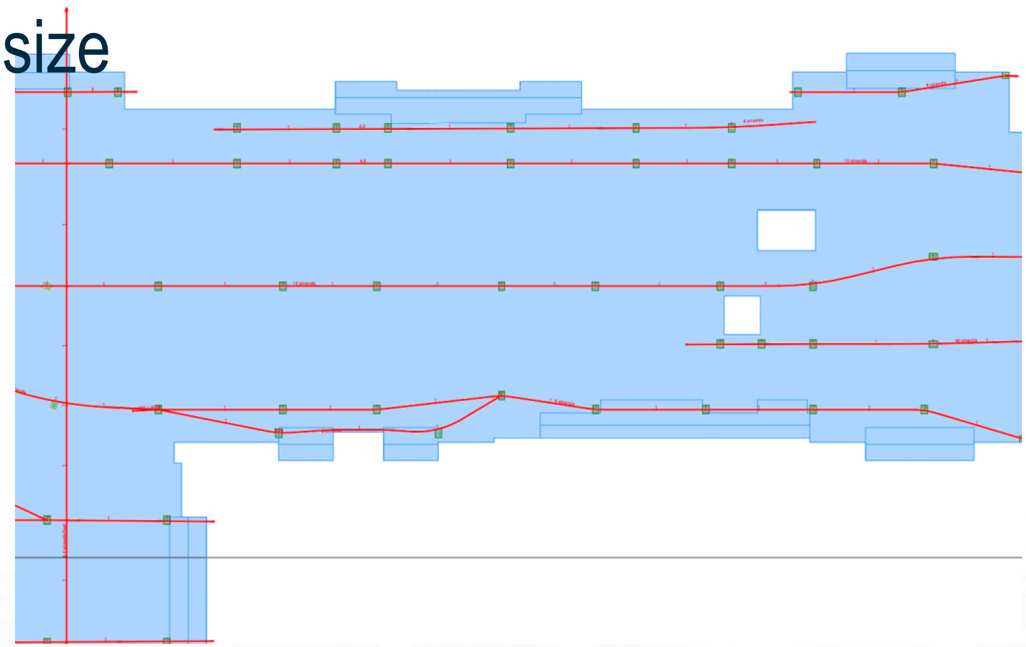
Manual Design

Concrete Costs								
Materials:	100	per	yd³	x	175.1	yd³	=	17510
Labor:	50	per	yd³	x	175.1	yd³	=	8754
Total:	150	per	yd³	x	175.1	yd³	=	26260
Post-Tensioning Costs								
Materials:	1	per	pounds	x	4083	pounds	=	4083
Labor:	0.5	per	pounds	x	4083	pounds	=	2041
Total:	1.5	per	pounds	x	4083	pounds	=	6124
Formwork Costs								
Materials:	1	per	ft²	x	5669	ft²	=	5669
Labor:	1	per	ft²	x	5669	ft²	=	5669
Total:	2	per	ft²	x	5669	ft²	=	11340
Mild Steel Reinforcing Costs								
Materials:	1000	per	tons	x	1.383	tons	=	1383
Labor:	500	per	tons	x	1.383	tons	=	691.3
Total:	1500	per	tons	x	1.383	tons	=	2074
SSR Costs								
Materials:	2	per	stud	x	0	studs	=	0
Labor:	1	per	stud	x	0	studs	=	0
Total:	3	per	stud	x	0	studs	=	0
Total Costs								
Materials:	5.052	per	ft²	x	5669	ft²	=	28640
Labor:	3.026	per	ft²	x	5669	ft²	=	17160
Total:	8.079	per	ft²	x	5669	ft²	=	45800

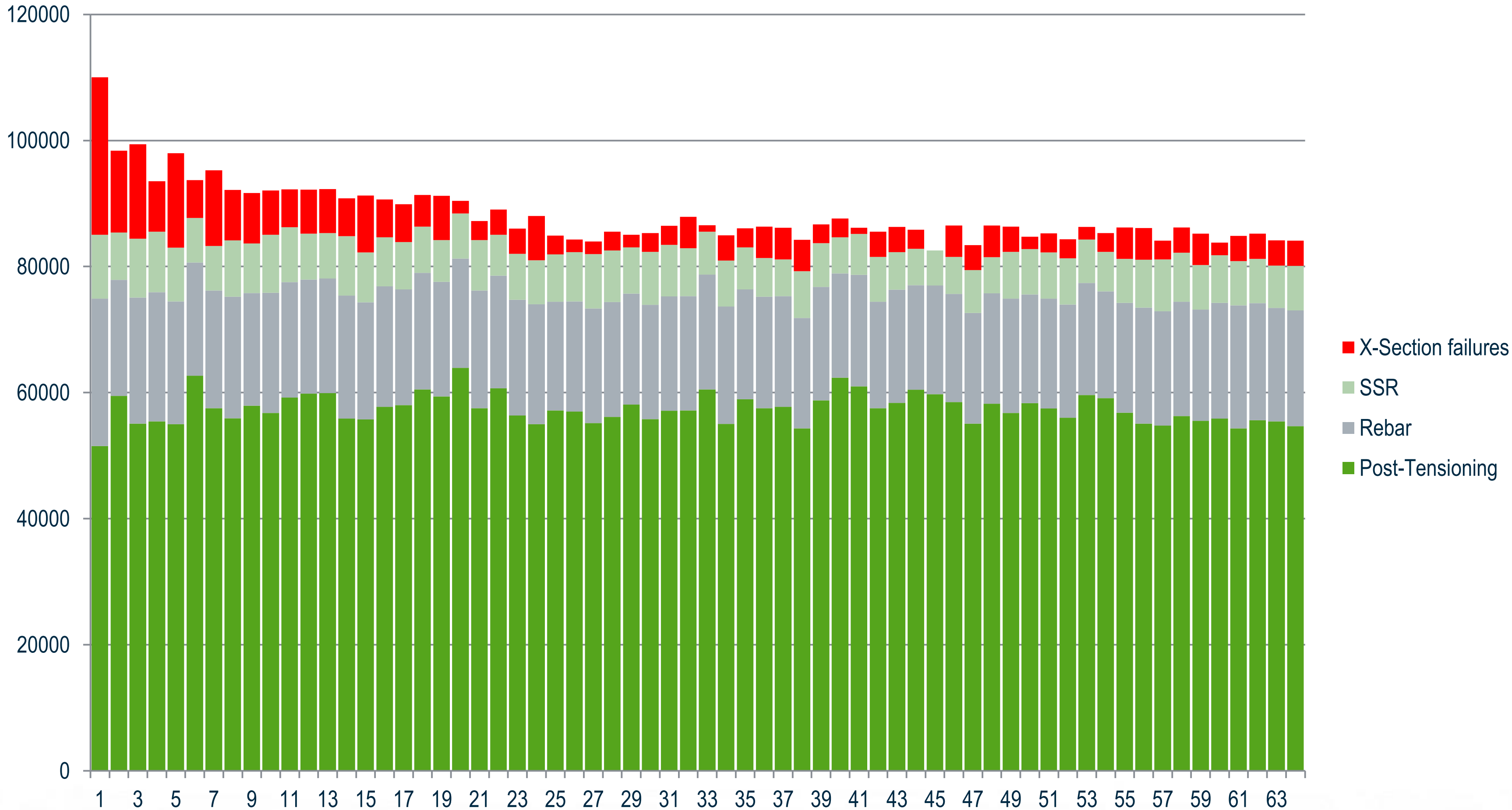
Optimized Design

Practical Application

- 50,000+ sf real world post-tensioned slab
- Approximately 28.5' typical spans
- 8" thick slab down to 6" minimum thickness in balconies
- 18" x 24" typical column size

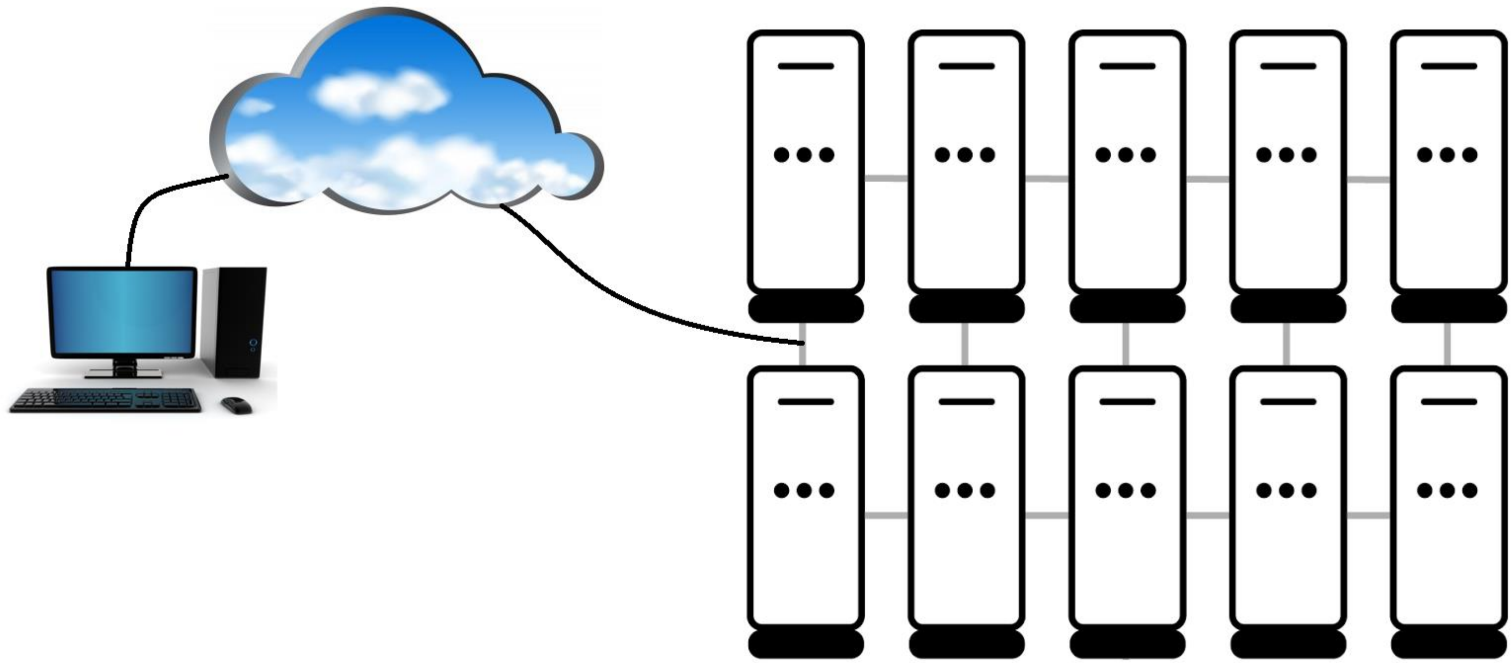


Practical Application

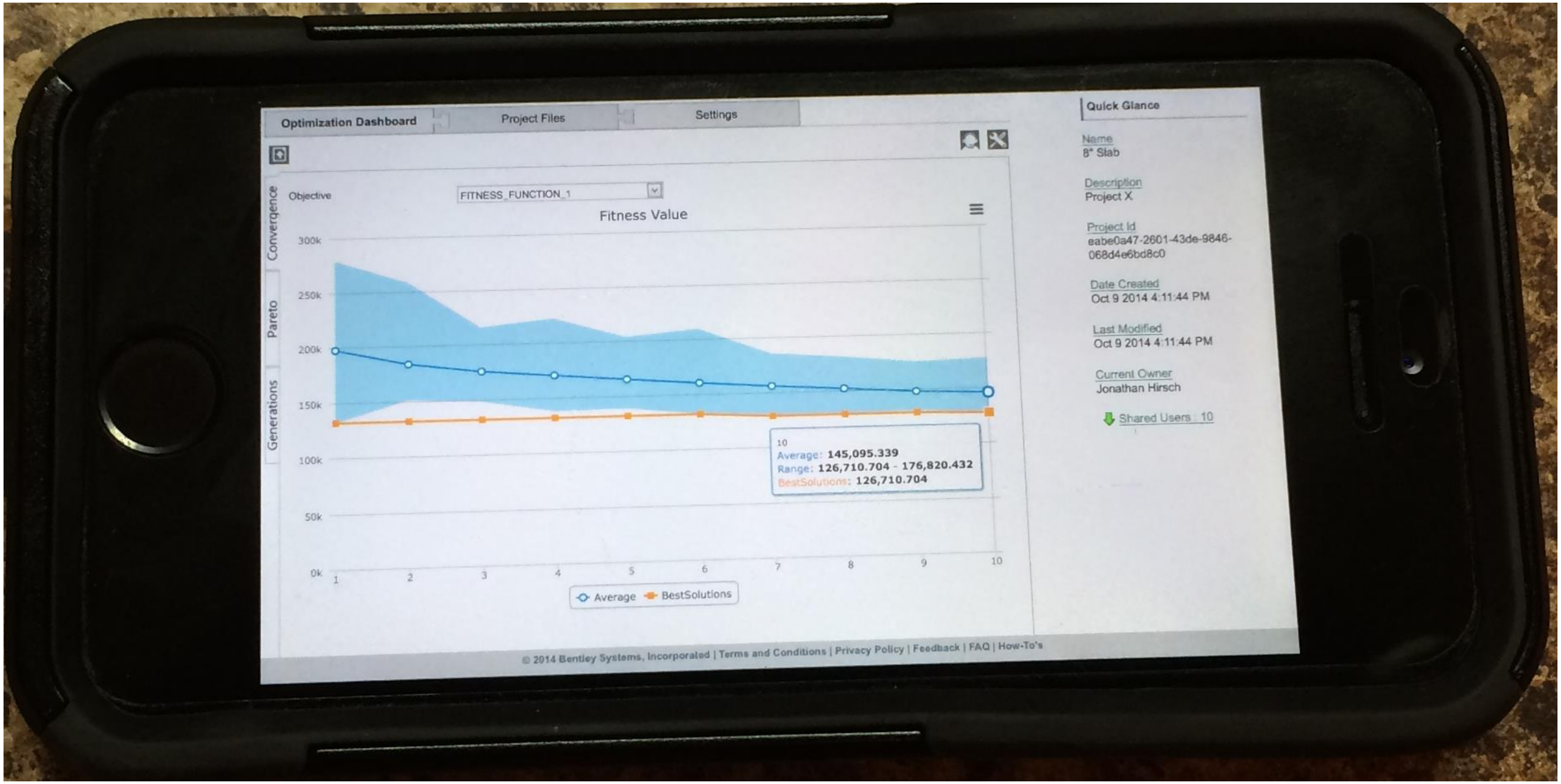


Practical Application

To the cloud!!!



Portability



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Advantages of Optimization

- Reduced design labor
- Comparison of many (thousand) designs to allow choice of optimal solution
- Fitness function can be written to include many parameters
  - Material and labor costs (PT, rebar, SSR, concrete)
  - Can include penalties for failed design criteria
  - Can include penalties to avoid undesirable performance aspects
- Can be run in the cloud to minimize solution time and not tie up the desktop

Future Work

- Calibrate failure penalties
- Further testing of cloud computing aspects
- Test genetic optimization parameters
  - Population size
  - Number of crossover points
  - Probability of creeping mutations
- Investigate other optimization algorithms

Questions?

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