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Behavior of Optimized Castellated Beam Under Cyclic-Quasi Static Loading

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ABSTRACT

Castellation process is one technique for increasing bending capacity for steel construction, especially in beam member. However, there are several parameters should be considered for obtaining an optimal castellated beam, such as opening space opening angle, opening ratio. This paper considered two cases optimized castellated beam which has been done before. Finite element analysis was performed for obtaining the behavior of optimized castellated beam. The previous research revealed that second case optimization was better than the first case optimization but in monotonic loading. Therefore, there must be a study for the optimized castellated beam on cyclic quasi-static loading condition. This study considered two optimized castellated beams subjected to cyclic quasi-static loading on cantilever beam to obtain the behavior of optimized castellated beam. The result shows that the second case optimization performance better than the first case optimization based on peak load and dissipation energy of the beam.

Keywords: Optimized castellated beam, cyclic quasi static, peak load

1. INTRODUCTION

Nowadays, the castellated beam becomes popular in civil engineering construction especially on building structures. The most advantage of using castellated beam is increasing in vertical bending stiffness. Castellated beam proves to be efficient for moderately loaded longer spans where the design is controlled by moment capacity or deflection [1]. But for obtaining the optimized castellated beam which has good ability, there are three variables must be considered in the design process which is opening ratio, opening space, and opening angle.

This paper presents the behavior of castellated beam after optimization process using fast multi swarm optimization. There are two cases of optimization which have been considered. The first case is optimization of opening angle and opening space with a constant opening ratio, and the second case is optimization of opening angle, opening space, and an opening ratio of a castellated beam. This two condition of optimization has been completed by [2]. The result revealed that the second case of optimization has better performance than the first case of optimization in case of monotonic loading. But there must be a consideration about the behavior on cyclic loading condition. Hence, in this study, the optimized castellated beam was performed on cyclic quasi-static loading condition.

2. LITERATURE REVIEW AND METHOD

A. Castellated Beam

Castellated beams are those beams which have opening its web portion. Castellated beams are fabricated by cutting the web of hot rolled steel (HRS) I section into a zigzags pattern and thereafter rejoining it over one another [3]. There are several advantages of using a castellated beam, such as increasing the bending capacity of the beam due to increasing of the total depth of the beam [4], reducing the total weight of the beam without greatly reducing its strength [5], less quantity of steel used [6]. Figure1 shows the geometry of castellated beam, where, D is overall depth after castellation, D_o is opening depth, t_f is flange thickness, t_w is web thickness, b is flange width, e is clearing opening space, S is gross opening space, α is an opening angle.

B. Fast Multi Swarm Optimization

Fast multi swarm optimization is one of optimization techniques that have a good ability for finding optimization variables. Fast multi swarm optimization is derived from particle swarm optimization (PSO) which was first proposed by [7]. The theory of PSO is based on the behavior of birds swarm or insect. of Individual action and the influence of other individuals within a group are consisted on social behavior. For example, a bird in a flock of birds. Any individual or particles behave in a distributed manner by using its intelligence and also influences the behavior of the collective group. Hence, if one bird finding his way or short to get to the food source, the rest of the group will also immediately follow that path in spite of far from the location of the group.

The basic equation of PSO used to update the position and location of the particle is:

$$v_{i,j}(t+1) = w v_{i,j}(t) + c_1 R_1 (p_{best,i,j} - x_{i,j}(t)) + c_2 R_2 (g_{best,i,j} - x_{i,j}(t)) \quad (1)$$

$$x_{i,j}(t+1) = x_{i,j}(t) + v_{i,j}(t+1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where: $v_{i,j}$ (t+1) is updated velocity of particle, $x_{i,j}$ (t+1) is updated location of particle, t represent the iteration-t, $p_{best,i,j}$ is local best location of particle at t-iteration, $g_{best,i,j}$ is global best location of particle at t-iteration. R_1 and R_2 are a random numbers from interval 0-1, c_1 and c_2 are particle acceleration constants, in this paper, $c_1 = c_2 = 2$, and w is positive inertia weight coefficient which is a function $°_{min}$ and $°_{max}$ as follow:

$$w_{(t)} = °_{max} - ((°_{max} - °_{min}).t / \max t) \quad (3)$$

In PSO, each particle shares the information with its neighbors. PSO combines the cognition component of each particle with the social component of all the particles in a group. Although the speed of convergence is very fast, Once PSO traps into local optimum, it is difficult to jump out of local optimum. Therefore, the addition of a mutation operator to PSO will enhance its global search capacity and thus improve its performance. In order to prevent of falling to a local optimum, a new technique using a combination of Cauchy mutation and crossover operation which is called fast multi swarm optimization (FMSO) was introduced [8]. Similar to distributed genetic algorithm, multiple swarm's ideas are very useful for speeding up the search. The new information of exchanging and sharing mechanisms of FMSO makes it converge fast to the global optimum.

Whenever the particle converges, it will "fly" to the personal best position and the global best particle's position. Due to this information of sharing mechanism makes the speed of convergence of PSO is very fast. Meanwhile, because of this mechanism, PSO cannot guarantee to find a global optimum value of a function. In fact, the particles usually converge to local optima. Without loss of generality, only function minimization is discussed here. Once the particles trap into a local optimum, in which $p_{best,i,j}$ can be assumed to be the same as $g_{best,i,j}$, all the particles converge to $g_{best,i,j}$. At this condition, the velocity's update equation becomes:

$$v_{i,j(t+1)} = \mu . v_{i,j(t)} \quad \text{.......................... (4)}$$

When the iteration in the equation (4) goes to infinite, the velocity of the particle $v_{i,j}$ will be closed to 0 because of $0 \leq \omega < 1$. After that, the position of the particle $x_{i,j}$ will not change, so that PSO has no capability of jumping out of the local optimum. It is the reason that PSO often fails on finding the global minimal value. To overcome the weakness of PSO discussed at the middle of this section, the Cauchy mutation is incorporated into PSO algorithm. The basic idea is that, the velocity and position of a particle are updated not only according to (1) and (2), but also according to Cauchy mutation as follows:

$$x_{i,j(t+1)} = x_{i,j(t)} + (v_{i,j(t)} \exp(\delta))\delta \quad \text{.......(5)}$$

Where, δ denotes Cauchy random numbers.

Since the expectation of Cauchy distribution does not exist, the variance of the Cauchy distribution is infinite so that Cauchy mutation could make a particle have a long jump. By adding the update equations of (5), PSO greatly increases the probability of escaping from the local optimum [8].

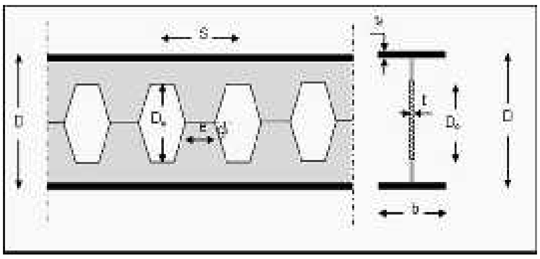

Fig 1. Geometry of castellated beam

For crossover operation, for rand () < q_c the crossover operation is taken as follows:

$$x_{i,j(t+1)} = (1-\sim).x_{i,j(t)} + \sim.p_{best,i,j}$$

(6)

$$v_{i,j(t+1)} = rand().(p_{best,i,j} - x_{i,j(t)})$$

(7)

Where α is random number with 0-1 interval, q_c is crossover rate.

C. Optimized Castellated Beam

Figure 2 shows the simply supported beam with a span length of 1 m which optimized and has been done by [2]. There was two cases optimization case used, the first case is optimization of opening angle, opening space with the opening ratio of 0.6 while the second case is optimization of opening angle, opening space, and opening ratio.

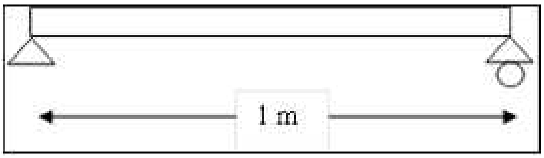

Fig 2. Beam structure for optimization process [2]

Table 1 shows the material and section properties used. The parent beam which used for castellation process was WF 200.100.8.5.5. The result obtained that the second case optimization was better than the first case optimization, this can be a cause of the fitness value of the second case is less than the first case. The fitness value of the second case and the first case was obtained from [2] was respectively 2.4187 x 1011 and 2.6249 x 1011. But this condition of optimization is monotonic loading, hence there must be a consideration if the beam is subjected to cyclic loading for knowing which has a better performance whether a first case or second case optimization.

3. RESULT AND DISCUSSION

For obtaining the behavior of optimized castellated beam, the finite element software ABAQUS used for modeling purpose [9]. The castellated beam was modeled using S4R element (Shell, 4-nodes with reduced integration) as shown in Figure 3.

Table 1. Material and section properties

Properties	Value
Overall depth (H)	200 mm
Flange width (b)	100 mm
Web thickness (t_w)	5.5 mm
Flange thickness (t_f)	8 mm
Yield stress (F_y)	240 MPa
Elastic modulus material (E)	200000 MPa

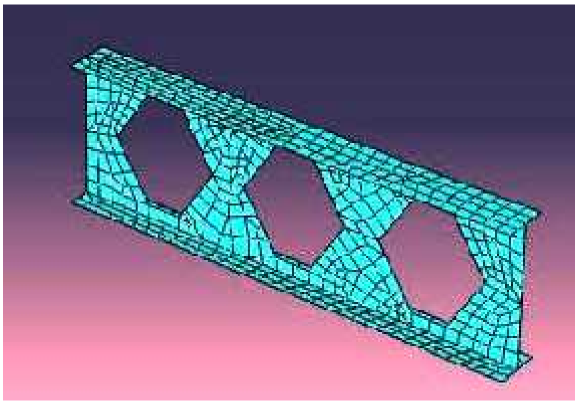

Fig 3. Meshing of castellated beam using S4R elemen

Figure 4 shows the boundary condition and the loading condition of the cantilever beam. The beam was fixed on the one edge of the beam while the other edge became the point of loading. Displacement controlled was chosen for cyclic quasi-static loading. The failure criteria of the beam were Von Mises stress. Therefore, the castellated beam was assumed perfectly plastic during the cyclic quasi-static loading with neglecting the local failure of the beam.

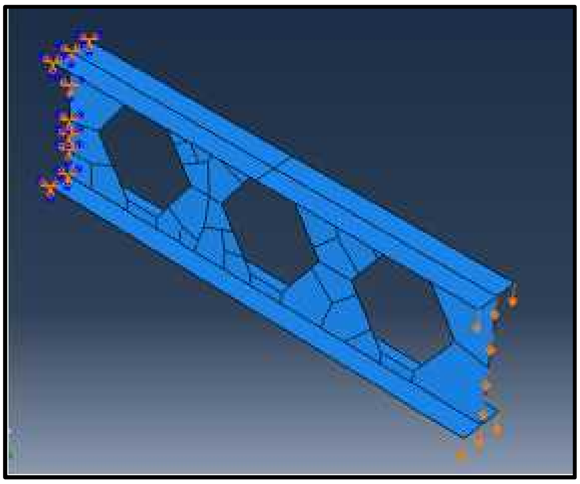

Fig 4. Boundary and loading condition

Figure 5 shows the relationship between the reaction force and the displacement for first case optimization and second case optimization due to cyclic quasi-static loading. The hysteresis loop of the second case optimization more “well-rounded” compared the hysteresis loop of the first case optimization. The peak load of first case optimization and second case optimization were 889.613 kN and 1895.78 kN with corresponding to displacement around 60 mm.

Based on Figure 5, the energy dissipation was 4.1571x105 kN-mm for the first case and 5.6419x105 kN-mm for the second case respectively. [10, 11] Polyarea function (MATLAB) has been used for area dissipation of the hysteresis loop for both case optimization. Based on that result, the energy dissipation of the second case was better than the energy dissipation of the first case optimization.

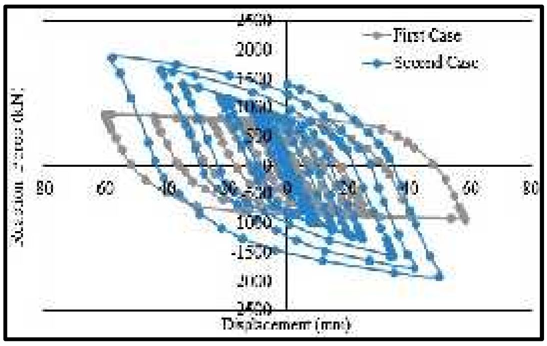

Fig 5. Reaction force vs displacement relationship under cyclic quasi static loading

4. CONCLUSION

A behavior of optimized castellated beam has been conducted in this paper. Based on the result, the second case optimization has better performance than the first case optimization. This can be concluded because of the peak load (maximum load) for second case optimization was 1895.78 kN while the first case optimization was 889.613 kN.

Moreover, the dissipation energy for the first case and second case was 4.1571x105 kN-mm for the first case and 5.6419x105 kN-mm respectively. The dissipation area for second case optimization is more “well rounded” compared by the first case optimization.

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