CYCLIC DEFORMATION BEHAVIOUR OF REINFORCED CONCRETE SHEAR WALLS

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SYNOPSIS

Alternately cyclic loading tests on shear walls were carried out to invetigate the fundamental cyclic behaviour of reinforced concrete shear walls. The representative hysteresis loop characteristics of RC- shear walls are clarified on the three types of cyclic loading with constant dislpacement amplitudes, with constant load amplitudes and with incremental displacement amplitudes. Specifically, the authors intend to examine the physical significance of the hyteresis loops, the energy absorption due to hysteresis and the low cycle fatigue of RC- shear walls by using an idealized mechanical model with equivalent compressive concrete bracing. Finally, the proposed mechanical idealization makes clear the hysteresis characteristics of RC-shear walls.

1. INTRODUCTION

Reinforced concrete shear walls recently have been recognized to play the most important role in the aseismic characteristics of the reinforced concrete buildings. This was shown in the recent earthquake damages of the modern RC-structures [4]. There are, however, few investigations [1] concerned with the behaviours until fracture of RC-shear walls subjected to cyclic loadings. This paper deals with the hysteresis loop characterstics, the energy absorption due to hysteresis and the low cycle fatigue to make clear the mechanism of fracture processes and the physical significance of hysteresis characteristics of RC-shear walls.

2. EXPERIMENTAL PROGRAM

The specimens were designed to represent a scale of one-fifth of the real reinforced concrete shear walls which are generally used in design. Details and dimensions of the specimens are shown in Fig. 2. The wall reinforcement ratio, p_w, is 0.3 %.

The test specimens were placed in the loading frame and subjected to cyclic lateral loadings, while one-third of the ultimate axial strength was constantly applied to the columns throughout the test. The shear force was applied diagonally by the oil jack with a load cell through the high strength steel rods (see Fig. 1).

Tests were carried out on the three types of loading program, i.e., (A) alternately cyclic loading with constant displacement amplitudes, (B) with constant load amplitudes, (C) with incremental displacement amplitudes, as summarized in Table-1.

3. HYSTERESIS LOOP CHARACTERISTICS

<u>Test</u> Representative cyclic behaviour of the test shear walls is

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experimentally shown by the hysteresis loop characteristics of the load versus displacement relationships in Figs. 3, 4 and 5. In Loading Type-A the repetition of the constant displacement resulted in decay of shear strength (see Fig. 3). In the hysteresis loops represented by Loading Type-B, deflection tends to increase as the loading cycle number increases. Ultimately, shear resistance deteriorated rapidly due to spalling down of the concrete in diagonal compression zone of a wall panel (Fig. 4). Fig. 5 shows the hysteresis loops for WC-7 in Loading Type-C, the envelope of which is nearly equal to the virginal Q-R curve for monotonic loading. Changes of the hysteresis loops are shown in the processes of progressive fracture of the test shear wall. The lateral force is carried mainly by a diagonal compression strut.

Analysis On the basis of the test results the shear carrying mechanism was assumed to consist of three elements , i.e. (1) surrounding frame, (2) compressive and tensile concrete braces and (3) tencile wall reinforcement brace, as shown in Fig. 7. Fig. 6 shows the idealized cyclic mechanical properties for each element. The load - displacement relationships for the test shear walls are analytically given by summation of shear resistance for each element as shown in Fig. 8, which shows that mechanism of the hysteresis loop characteristics is well explained by the simplified model of the RC-shear wall. In detail of Fig. 8, the calculated results are indicated by the dotted line and the test results by the solid line.

4. CHARACTERISTICS OF HYSTERESIS LOOP AREA [2]

The hysteresis characteristics of the concrete in compression zone of a wall panel can be supposed to play a major role in the hysteresis characteristics of the test shear wall in the inelastic range. This basic assumption based on the experimental and analytical results presented above was attempted to demonstrate from the point of view of the characteristics of hysteresis loop area which corresponds to the dissipated energy (see Fig. 12).

Plain Concrete Hysteresis curves for plain concrete are idealized as shown in Fig. 9 so that the following equations (A), (B) and (C) can be obtained to calculate the hysteresis loop area for plain concrete.

$$(A),\quad \frac{A_{Nc=1}}{F_c} = -\frac{1}{48}\varepsilon_p^4 + \frac{1}{12}\varepsilon_p^3 + \frac{1}{6}\varepsilon_p^2, \qquad \frac{A_{Nc\geqq 2}}{F_c} = \frac{1}{96}\varepsilon_p^4 - \frac{1}{12}\varepsilon_p^3 + \frac{1}{6}\varepsilon_p^2,$$

$$(B),\quad \frac{A_{Nc=1}}{F_c} = \frac{4}{3} - \frac{2}{3}\sqrt{1-\frac{\sigma_p}{F_c}}\left(2+\frac{\sigma_p}{F_c}\right) - \frac{1}{3}\left(\frac{\sigma_p}{F_c}\right)^2, \qquad \frac{A_{Nc\geqq 2}}{F_c} = \frac{1}{6}\left(\frac{\sigma_p}{F_c}\right)^2,$$

$$(C),\quad \frac{{}_{p-1}A_p}{F_c} = \left(\frac{1}{6}\varepsilon_p^2 + \frac{1}{12}\varepsilon_p^3 - \frac{1}{48}\varepsilon_p^4\right) - \left(\frac{1}{6}\varepsilon_{p-1}^3 - \frac{1}{32}\varepsilon_{p-1}^4\right),$$

where $A_{Nc=1}$ is the hystersis loop area in the first cycle, $A_{Nc\geqq 2}$ is the hysteresis loop area after the 1st cycle, σ_p/F_c is the constant stress amplitude and ${}_{p-1}A_p$ is the hysteresis loop area when the strain ε_{p-1} proceeds to ε_p. These equations can predict well the hysteresis loop area for the plain concrete under the repeated loading (see Fig. 10) [3].

Reinforced Concrete Shear Wall The equations (A), (B) and (C) for the hysteresis loop area of the plain concrete are applicable to calculating the hysteresis loop area of RC-shear walls in the respective loading conditions of Type-A, B and C. In applying these equations, the test RC-shear wall is idealized to a significant mechanical model with the compressive concrete brace which resists the shear force, Q, in the elasto-plastic range, as shown in Fig. 11. Fig. 13 shows the comparison of the experimental and the computed results by using the Eqs. (A), (B) and (C), with the solid- and the dotted- line respectively.

The equations for the hysteresis loop area are generally conservative for the experimental results of the test shear walls. This is due to the crushing of the wall panel concrete under the complex states of stresses and the characteristics of hysteresis loop area for the surrounding frame.

5. LOW CYCLE FATIGUE [2]

Fig. 14 shows the relation between increase of srain and number of cycles for the compressive concrete brace of the test shear walls in Loading Type-B and further the relation between load ampitude and number of cycles until fracture for the RC-shear walls, compared with the repeated loading test results of the plain concrete [3]. The fatigue characteristics of the RC-shear walls tend to correspond to those of the plain concrete.

6. CONCLUDING REMARKS

The following conclusions are derived on the basis of the results presented herein.
(1), Representative hysteresis loop characteristics of the RC-shear walls are made clear experimentally as well as analytically.
(2), The cyclic shear behaviour of the RC-shear walls can be clarified by the simplified mechanical idealization of concrete bracings such as shown in Fig. 7.
(3), The idealized model as shown in Fig. 11 is useful for evaluation of the energy absorption-characteristics of the RC-shear walls.
(4), The concrete element largely affects the fatigue characteristics of the RC-shear walls.

7. BIBLIOGRAPHY

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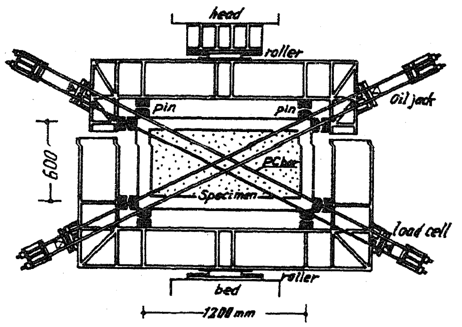


Fig. 1 Loading System

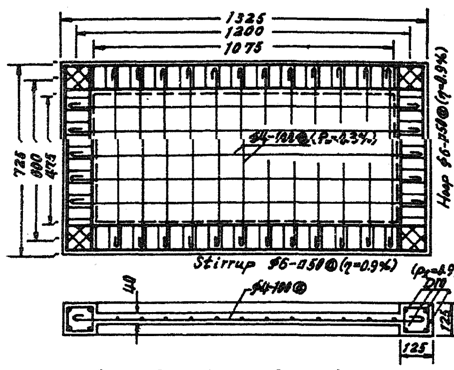
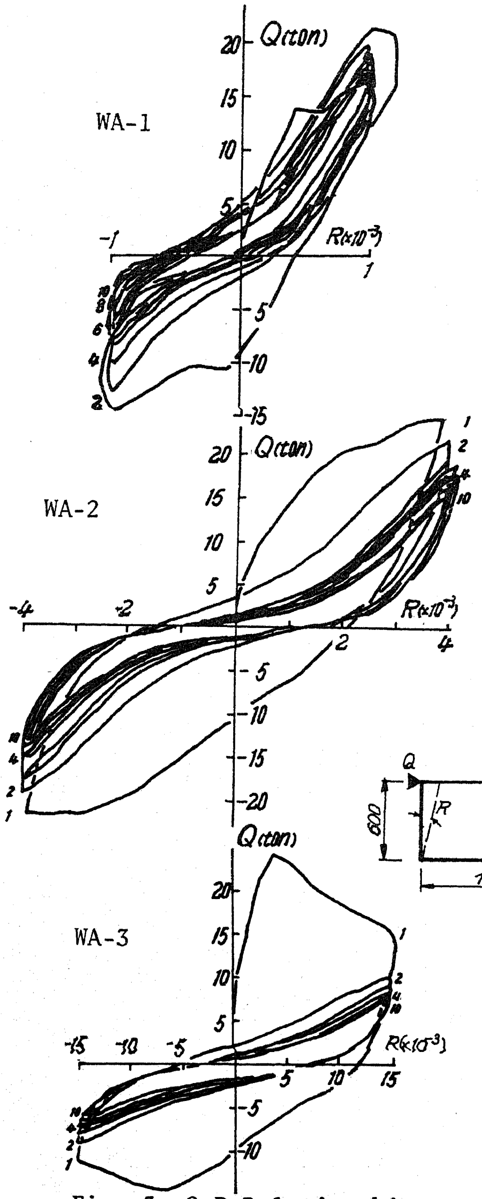
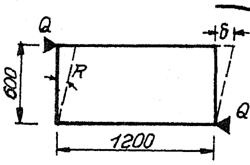


Fig. 2 Test Specimen





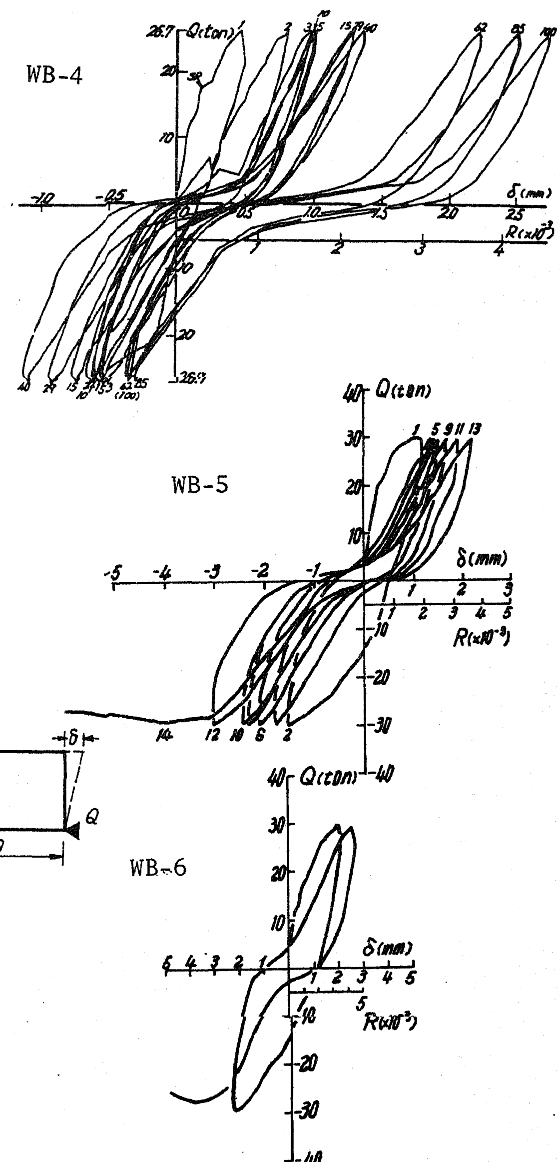


Fig. 3 Q-R Relationships (Loading Type-A)

Fig. 4 Q-R Relationships (Loading Type-B)

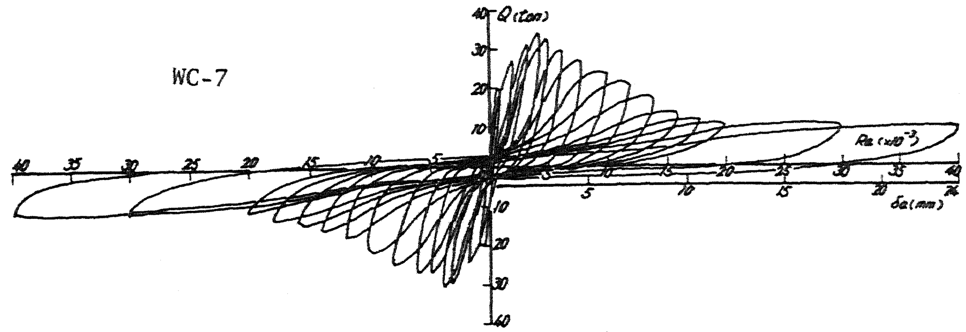


Fig. 5 Q-R Relationships
(Loading Type-C)

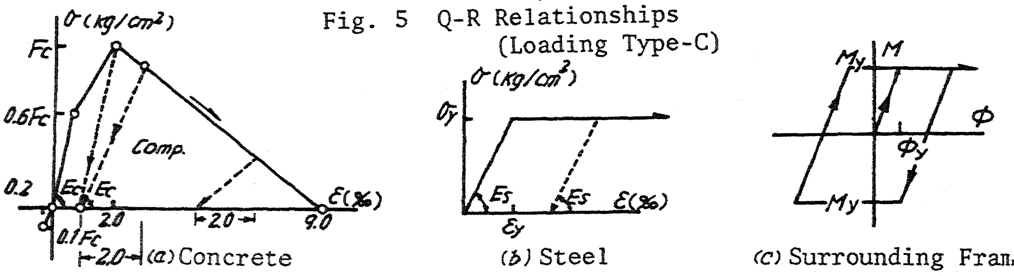


Fig. 6 Mechanical properties

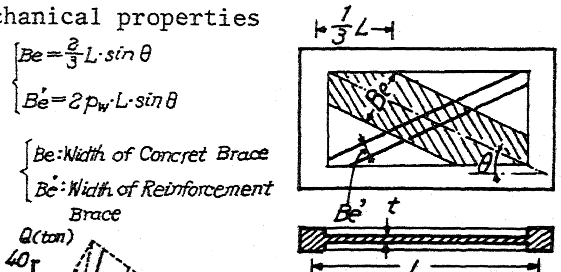
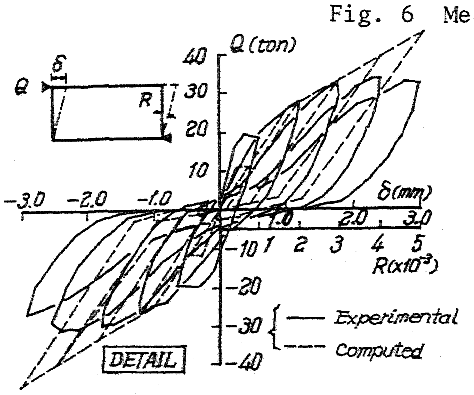


Fig. 7 Idealized Model



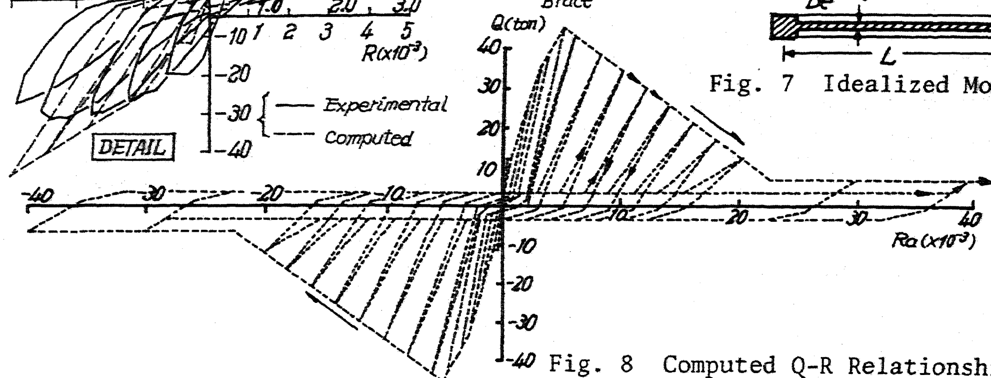
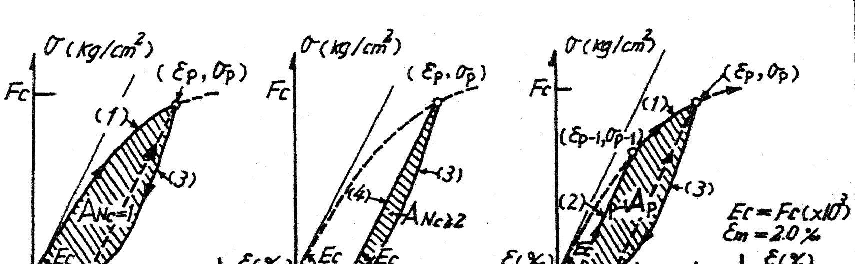


Fig. 8 Computed Q-R Relationships
(Loading Type-C)



(1) $\frac{\sigma}{F_c} = -\left(\frac{\varepsilon}{\varepsilon_m}\right)^2 + \frac{2\varepsilon}{\varepsilon_m}$ $(0 \leq \varepsilon/\varepsilon_m \leq 1)$

(2) $\frac{\sigma}{F_c} = 2\left(\frac{\varepsilon}{\varepsilon_m} - \frac{\varepsilon_{p-1}}{\varepsilon_m}\right) + \frac{\sigma_{p-1}}{F_c}$

(3) $\frac{\sigma}{F_c} = \frac{4F_c}{\sigma_p}\left\{\frac{\varepsilon}{\varepsilon_m} - \left(\frac{\varepsilon_p}{\varepsilon_m} - \frac{\sigma_p}{2F_c}\right)\right\}^2$

(4) $\frac{\sigma}{F_c} = 2\left(\frac{\varepsilon}{\varepsilon_m} - \frac{\varepsilon_p}{\varepsilon_m}\right) + \frac{\sigma_p}{F_c}$

Fig. 9 Idealized Stress- Strain Curves for Plain Concrete

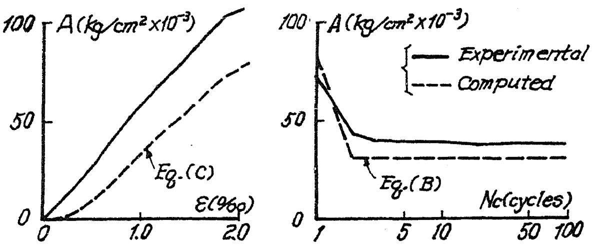


Fig. 10 Processes of Hysteresis Loop Area for Plain Concrete

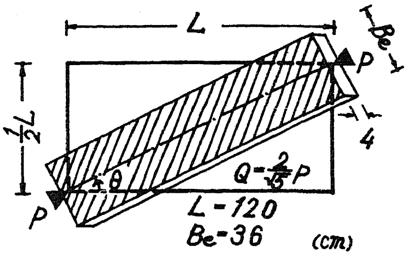


Fig. 11 Mechanical Idealization

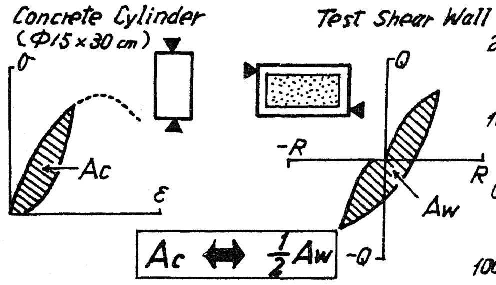


Fig. 12 Relation between Plain Concrete and RC-shear Wall

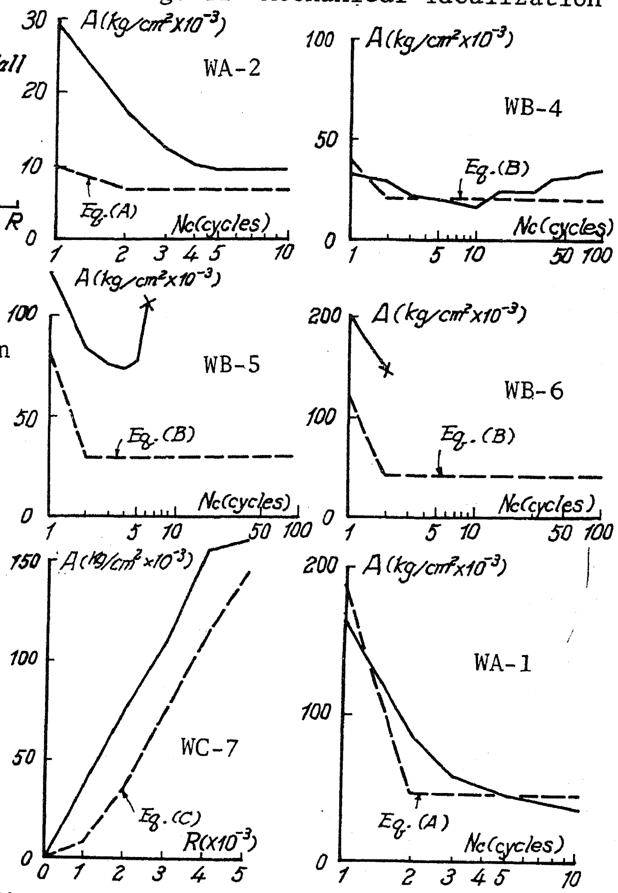


Fig. 13 Characteristics of Hysteresis Loop Area for RC-Shear Wall

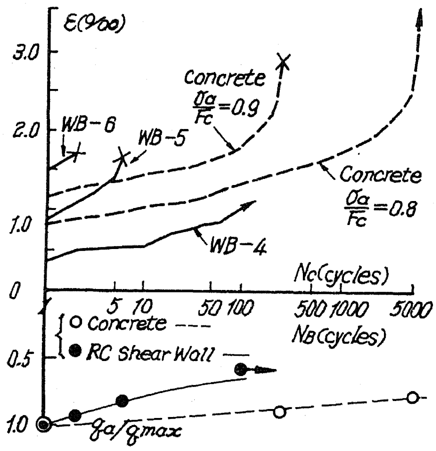


Fig. 14 Fatigue of RC-Shear Wall and Plain Concrete

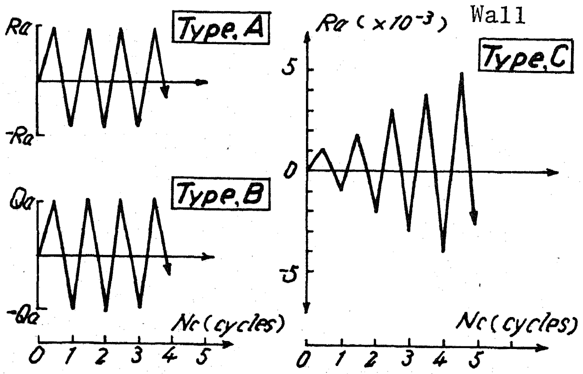


Fig. 15 Loading schedule

Table-1 Testing Program

Specimen Mark	Loading Type	Variable	Concrete Comp. Strength (Fc)
WA-1	A	$Ra = 1\times10^{-3}$	317 (kg/cm²)
WA-2		$Ra = 4\times10^{-3}$	302.5
WA-3		$Ra = 15\times10^{-3}$	290.3
WB-4	B	$Qa = 0.6\,Q_{max}$	345
WB-5		$Qa = 0.8\,Q_{max}$	286.1
WB-6		$Qa = 0.95\,Q_{max}$	279
WC-7	C	$R = 1\times10^{-3}$ pitch	276.7