

OBSERVATIONS ON THE TERNARY QUADRATIC EQUATION

$$X^2=24\alpha^2+Y^2$$

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Abstract. The ternary quadratic equation $X^2=24\alpha^2+Y^2$ is considered. Employing its non-zero integral solutions, relations among a few special polygonal numbers are determined.

1. INTRODUCTION

In [1,8,10], different patterns of m-gonal numbers are presented. In [2], explicit formulas for the ranks of triangular numbers which are simultaneously equal to pentagonal, decagonal and dodecagonal in turn are presented. In [3,5,6], the relations among the pairs of special m-gonal numbers are generated through the solutions of the ternary quadratic equation are determined. In [4,7,9], the binary quadratic equations are considered and relations between special polygonal numbers are obtained through its solutions.

In this communication, we consider the ternary quadratic equation given by $X^2=24\alpha^2+Y^2$, where α is a non-zero integer and obtain the relations among the pairs of special m-gonal numbers generated through its solutions.

2. NOTATION

- $t_{3,N}$ · Triangular number of rank N
- $t_{5,P}$ · Pentagonal number of rank P
- $t_{6,Q}$ · Hexagonal number of rank Q
- $t_{7,H}$ · Heptagonal number of rank H
- $cp_{8,M}$ · Centered octagonal number of rank M
- $g_4(G)$ · 4-gram number of rank G

3. METHOD OF ANALYSIS

Consider the Diophantine equation

$$X^2=24\alpha^2+Y^2 \tag{1}$$

where α is a non-zero integer. The smallest non-zero integer solution of the Pellian equation $X^2=24\alpha^2+1$ is given by $\alpha_0=1, X_0=5$. Thus the general form of non-trivial integral solutions (α_n, X_n) are given by

$$\begin{aligned} \alpha_n &= \frac{Y}{4\sqrt{6}} \left[(5 + 2\sqrt{6})^{n+1} - (5 - 2\sqrt{6})^{n+1} \right], \quad n = 0, 1, 2, \dots \\ X_n &= \frac{Y}{2} \left[(5 + 2\sqrt{6})^{n+1} + (5 - 2\sqrt{6})^{n+1} \right] \end{aligned} \tag{2}$$

Case 3.1

Let N and Q be the ranks of the n^{th} Triangular and Hexagonal numbers respectively.

The choice

$$X=2N+1; Y=4Q-1 \tag{3}$$

in (1) leads to the relation “ 2 times triangular number – 2 times hexagonal number = a nasty number” From (2) and (3), the values of ranks of Triangular numbers are found to be

$$N_n = \frac{4Q-1}{4} \left[(5 + 2\sqrt{6})^{n+1} + (5 - 2\sqrt{6})^{n+1} \right] - \frac{1}{2}, \quad n = 0,1,2, \dots \text{ and } Q \in \mathbb{Z}^+ - \{0\}$$

Numerical examples are illustrated in the table 3.1

Table 3.1

Q	$t_{6,Q}$	N_n $n = 0,1,2, \dots$	t_{3,N_n} $n = 0,1,2, \dots$
1	1	7,73,727,....	28,2701,264628,....
2	6	17,171,1697,...	153,14706,1440753,....
3	15	27,269,2667,...	378,36315,3557778,...

Case 3.2

Let N and P be the ranks of the n^{th} Triangular and Pentagonal numbers respectively.

The choice

$$X=2N+1; Y=6P-1 \tag{4}$$

in (1) leads to the relation “ 2 times triangular number – 6 times pentagonal number = a nasty number” From (2) and (4), the values of ranks of Triangular numbers are found to be

$$N_n = \frac{6P-1}{4} \left[(5 + 2\sqrt{6})^{n+1} + (5 - 2\sqrt{6})^{n+1} \right] - \frac{1}{2}, \quad n = 0,1,2, \dots \text{ and } P \in \mathbb{Z}^+ - \{0\}$$

Numerical examples are illustrated in the table 3.2

Table 3.2

P	$t_{5,P}$	N_n $n = 0,1,2, \dots$	t_{3,N_n} $n = 0,1,2, \dots$
1	1	12,122,1212,....	78,7503,735078,....
2	5	27,269,2667,...	378,36315,3557778,...
3	12	42,416,4122,....	903,86736,8497503,....

Case 3.3

Let N and H be the ranks of the n^{th} Triangular and Heptagonal numbers respectively.

The choice

$$X=6N+3; Y=10H-3 \tag{5}$$

in (1) leads to the relation “ 18 times triangular number – 10 times heptagonal number = a nasty number” From (2) and (5), the values of ranks of Triangular numbers are found to be

$$N_n = \frac{10H-3}{12} \left[(5 + 2\sqrt{6})^{n+1} + (5 - 2\sqrt{6})^{n+1} \right] - \frac{1}{2}, \quad n = 0,1,2, \dots \text{ and } H \equiv 0 \pmod{3}$$

Numerical examples are illustrated in the table 3.3

Table 3.3

H	$t_{7,H}$	N_n $n = 0,1,2, \dots$	t_{3,N_n} $n = 0,1,2, \dots$
3	18	22,220,2182,...	253,24310,2381653,....
6	81	47,465,4607,...	1128,108345,10614528,....
9	189	72,710,7032,...	2628,252405,24728028,...

Case 3.4

Let M and G be the ranks of the n^{th} Centered octagonal and 4-gram numbers respectively.
The choice

$$X=8M+3; Y=8G-4 \tag{6}$$

in (1) leads to the relation “ 4 times centered octagonal number – 4 times 4-gram number = a nasty number” From (2) and (6), the values of ranks of centered octagonal numbers are found to be

$$N_n = \frac{8G-4}{16} \left[(5 + 2\sqrt{6})^{n+1} + (5 - 2\sqrt{6})^{n+1} \right] - \frac{1}{2}, \quad n = 0,1,2, \dots \text{ and } G \in \mathbb{Z}^+ - \{0\}$$

Numerical examples are illustrated in the table 3.4

Table 3.4

G	$g_4(G)$	M_n $n = 0,1,2, \dots$	cp_{8,M_n} $n = 0,1,2, \dots$
1	1	2,24,242,.....	25,2401,235225,.....
2	9	7,73,727,...	225,21609,2117025,...
3	25	12,122,1212,...	625,60025,5880625,.....

CONCLUSION

To conclude, one may determine the relations between the special polygonal numbers employing the integer solutions of various ternary quadratic equations.

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