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An Analysis of the Association between Electric Parameters Recorded Across the Fractured Limbs and Configurations of the Bone Fracture.

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ABSTRACT

This prospective study was done in 32 fractures or bone defects of tibia. After fracture debridement, Ilizarov external fixator with Teflon coated carbon rings were applied in consenting patients. DC voltage is applied to the K- wires passed through the bone above and below the fracture site in steps of 0.1 V and the current is recorded for each step voltages (0.1, 0.2….1.0 V). The current was plotted in a graph versus the days of treatment and simultaneously compared with alongside X-rays. All the 32 cases which exhibited a stabilization of current flow with a fixed current value possibly point to the calcification of callus and consequential strengthening of tissue in the fracture site. This also coincided with the radiological and clinical healing. The disarray electrical environment in the early callus stabilized (asymptotic) when the fracture healed. We analyzed the association between current recorded across the fractured limb and fracture configuration. There were three types of graphs matching three fracture patterns. The types of the graphs differed with shape of the fracture and stage of healing, with irregularity increasing when fracture ends had unstable fracture configuration.

Key words: Ilizarov, Direct Current, Configuration, unstable, fracture

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INTRODUCTION

The logical end of a fracture treatment is its union. Identifying this union is essential both to help in deciding the need for procedures augmenting union or if the fracture has united to remove the fixator. In open fractures special ring fixators called the Ilizarov are used. Routine X-rays help in assessing the fracture healing. In augmenting fracture union in non-unions FDA has approved electric stimulation [1] and there are numerous methods [2-17]. There are a few current studies that try electric stimulation as a method to monitor fracture healing [18-22]. In two previous works [19, 20] there was an attempt of analysis of shapes of the fracture with electric current output on a small number of patients. This work is on a large number of patients.

METHODOLOGY

This prospective study done in 32 tibia fractures patients after getting institutional review board approval. They had either a fracture or bone defect of tibia of both sexes from fifteen to seventy years. In each patient of this group the fracture site was debrided and fixed with Ilizarov external fixator with carbon rings. After explanation with audio-visual aids about the relatively new technique of diagnostic electric stimulation, the patient is given the autonomy of selecting either this or only X-rays for the purpose of follow up.. In the same period 32 patients preferred only radiographs and are not part of the study. The application of the DC and the method of follow up are done as per methodology discussed in our previous papers. [18-22]However we repeat for easy understanding.

The DC voltage source (Scientech®) shown in Figure1 has an output range of DC voltages between 0.1 and 1 V and current rating of one Ampere. The current voltage is applied to the K-wires which were passed through the bone above and below the fracture site. The voltage was increased from 0.1 to 1 volt in steps of 0.1 V and the current is recorded for each step voltages (0.1, 0.2….1.0 V). Thus, the voltage was kept constant at 0.1 to 1 volt for all the cases and the current output was measured. Similar procedure was repeated during the follow-up of patients. While applying the DC voltage there was no discomfort felt by the patients. These cases were also followed with radiographs for healing. In all cases (except in cases 4 and 5 which had corticotomy) the distances between the rings were constant. The current was plotted in a graph versus the days of treatment and simultaneously compared with X-rays.The details of these patients like age, sex, site of the fracture, general diseases, delay between injury and the treatment, date of application of the rings, day of starting of stabilization of the current, the baseline current reading during the stabilization for these patients and day of ring removal, follow up after the apparatus removal are given in table 1. We analysed the association between electric parameters recorded across the fractured limb and fracture configuration.

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S.NO	AGE	TYPE	SITE	SEX	GEN	OTHER P	DA OST	BASE MA	DORR	FU M
1	65	3	U	M	ASTH	PLASTER	37	490	70	52
2	37	2	M	M	N	ILN	137	720	158	51
3	55	2	M	M	DM	EX FIX	91	250	134	51
4	25	GAP	M /L	M	N	EF/FLAP	292	30	355	51
5	39	GAP	M	M	IHD	EF SSG	189	130	243	47
6	17	1	L	M	N	PLASTER	110	470	187	46
7	50	1	L	M	N	PLASTER	56	380	133	45
8	40	2	L	F	N	PALSTER	50	140	98	38
9	29	COM 2	M	M	N	EX FIX	85	110	120	36
10	30	2	U	M	N	PLASTER	106	140	127	30
11	30	2	M	M	N	PLASTER	67	50	82	26
12	35	2	M	M	N	PLASTER	45	49	65	26
13	28	COM 2	L	M	N	CAL	160	80	159	25
14	28	2	M	M	N	EX FIX	67	120	84	25
15	60	2	L	M	N	PLBG	45	59	59	24
16	45	2	L	M	N	PLASTER	49	156	59	24
17	50	2	L	F	N	PLASTER	38	135	50	24
18	40	COM 2	M	F	N	PLASTER	28	240	38	21
19	45	COM2	M	M	N	EXFIX	75	140	105	21
20	35	2	L	M	N	EX FIX	95	110	115	20
21	29	2	M	M	N	PLASTER	50	139	97	20
22	30	2	M	M	N	EX FIX	140	80	150	20
23	32	COM2	M	M	N	EX FIX	85	59	100	19
24	26	COM 2	M	M	N	EX FIX	92	50	112	19
25	39	2	L	M	N	EX FIX	50	100	70	16
26	35	2	M	M	CRF	PLASTER	48	169	102	16
27	42	COM 2	U	M	N	PLASTER	48	340	110	16
28	35	COM 2	M	M	N	EX FIX	104	140	129	12
29	35	SEG	M	M	N	EX FIX	105	120	120	6
30	30	2	M	M	N	ILN10-11	210	230	220	4
31	40	2	L	M	N	EX FIX	90	110	110	4
32	45	2	L	M	N	EX FIX	86	100	106	4

Table 1: Cases treated with Ilizarov rings followed up with X-rays, clinical assessment, and electrical conduction, and the number of X-rays taken during their follow up

Key to the table 1. Type 1→Transverse fracture Type 2→Oblique fracture Comm→ With communition(broken Type3 →Irregular fracture with gap	
SITE	Upper, middle or lower shaft of tibia.
SEX	Male or Female
GEN	Diabetes, Asthma, CRF , N= Normal
OTHER P	Other Procedures
DA OST	Day of stabilization of current
BASE	Baseline current
DORR	Day of Ring removal
FUM	Follow Up in Months

One case example of current out-put matching the stabilization is illustrated here-under. This is a 25 year old male, a non- diabetic with an open fracture of middle third of his right leg with bone loss. After blood transfusions and stabilizing his general condition under spinal anesthesia, his fracture site was cleared of all debris and was stabilized with pins purchasing the bone and was coupled to each other by rods called the external fixator on the same day of injury as seen in figure 2. Four weeks later the patient developed necrosis of bone ends which was removed as seen from the X-rays in figure 3 and 4 resulting in further bone gap of eight cms in mid leg. Teflon coated carbon Ilizarov construct was applied to stabilize the fracture defect. The bone in the upper part of leg was carefully cut transversely purposely. Initial X-rays were taken to ascertain the position of the wires, fracture reduction and completion of corticotomy. After a wait of 10 days to allow new bone to form, the cut bone is slowly transported down by turning the nuts rate of 1mm per day till it touched the lower fragment. (internal bone transport) when an open approximation of the bone ends was done. These events are presented in figures 5 to 13. Here there were two sites of recording (the fracture site and the corticotomy). Unlike therapeutic electric stimulation where ends of the fractured bones need to be in contact, the present case is only a diagnostic electric stimulation and we wanted to monitor the electric events of the fracture gap as the bone is being moved by this new method. The current recorded during the time of X-rays is presented near the X-rays. The patient was observed for wound healing and recording and was discharged. During post-operative visits, X-ray assessment of healing of the fracture site and corticotomy site are presented in figures 14 to 22, at last he is seen comfortably loading his injured limb with the ring fixator in figure 23.

The current variations as fracture healing proceeded are graphically presented in figures 26 and 27 for corticotomy and fracture respectively. Figures 28 and 29 show the current variation for 0.7 V for better understanding for corticotomy and fracture respectively. In these graphs, there was irregularity till the transport was proceeding i.e. up to 124 days. The earliest sign of healing (fracture callus) was seen only in the 292nd day X-rays, i.e. five months after stopping the transport (Figure 20) and current output reading at this time was 30m A for the fracture site and 250mA for the corticotomy site for a DC Volt of 0.7 V. He was able to load the limb comfortably. Later on 306th and the 355th day's current output was again the same as earlier reading for both fracture and corticotomy sites respectively. This stabilization of the current flow matched his ability to load the fractured limb painlessly with the Ilizarov apparatus. X-rays taken on 306th day and the 355th day (figures 21and 22) also showed progressive healing signs-the last X-ray showing solid union. He was able to load the limb painlessly as seen from figure 23**.** Being a pilot study, we did not risk removing the ring only based on this new method- on 355th day, the apparatus was dynamised and removed on 358th day and the limb was placed first in a walking plaster and a month a tibial brace. The total number of X-ray views after ring application to removal is 34. Two year after the patient had any re-fractures or angulation (figure 24). At present the patient is walking unaided and can stand on the affected limb as seen from the figure 25.

RESULTS AND DISCUSSION

In the study, all the 32 cases exhibited a stabilization of current flow with a fixed current value possibly point to the calcification of callus and consequential strengthening of tissue in the fracture site. This also coincided with the radiological and clinical healing. The irregularity in the beginning in all 32 cases may be apparently attributed to disarray electrical environment in the early callus which stabilized to a flat line (asymptotic) when the fracture healed. Bone collagen fibers, when sliding past each other, alleged to cause a piezoelectric effect by shearing force. [23] But actually these are small currents to interfere with the applied DC current. [24] When electric potentials were recorded near healing skin wounds, there were stages of maximal strength and voltage which progressively fell down to a baseline, i.e. asymptotic. [25] This original irregularity was credited by another worker, to cellular and vascular processes in the early phase of callus formation. [26]

In this study, with insulating the soft tissues from conducting is difficult, the question is where the electrical conduction is taking place. To understand this, an example of an ECG may be considered [22]. According to D.J.Rowlands 'Electrocardiography developed empirically and its basic diagnostic criteria remain empirical'' More than 100 million 12 lead ECGs are recorded annually around the world. [27] ECG leads read only from the skin over the heart and the consequential wave-pattern is assumed to have began from the heart as pattern of waves matched the contraction of heart, for example ' p' wave synchronizing with atrial contraction. Likewise if the conductivity of other tissues except the bone is assumed to be the identical ahead of and after healing, then only the fractured bone is the dynamically changing tissue, as evaluated by physical examination and X-rays. Thus in our study, these changes observed in the graph constructed with current versus days for definite voltage should have cropped up from proceedings of the fracture healing process. [28] In all 32 cases, we had difficulty in insulating the tissues around the bone and the study appears empirical but the stabilization in the current versus days curve matched the progress of fracture healing. Hence it can be considered as a conduction study across the fractured limb. This is evident also from clinical assesment of the fracture with comfortable loading of a limb with apparatus with the nuts loosened.

Analysis of type of fracture

A study is undertaken to analyse the type of fracture. From the current vs day graph for the patients it was observed that there were three type of graphs and these patterns were matching three fracture patterns as illustrated side by side.

Type 1 graph. Figures 30 and 31 show the relation between current vs days for patients 6 and 7 of middle third tibial fractures. The sixth patient who had a short oblique fracture showed stabilization at 98 days and seventh patient with a transverse fracture stabilized in 58 days. In both these cases, except in the very beginning of the treatment period, there were no oscillations in the current versus days graph. Both of them had negligible gap, excellent stable bone contact with very minimal comminution thus resisting slipping (only two cases were of this type). This we designate as Type 1.

They can be further sub classified based on angle of fracture as (i) horizontal fracture with bone loss at edges as shown in figures 32 and 33 (ii) Inclined fracture [short oblique fracture] with angle less than 30 degree and almost no gap as shown in figure 34. We assume that the less irregularity in the graph is perhaps due to the stability at the fracture site in these two cases because of the shape of the fracture transverse or short oblique.

Type 2 graph . Figures 35,36 and 37 show the current versus days graph for the patients' number 2, 3 and 8 to 30 with oblique fractures involving the middle and lower third tibiae. (Constituting the maximum of 27 cases). We observed that, the undulations in current measurement are steady without any razor-sharp spikes and kept on till the end of the treatment period and later it becomes stable. These are seen in fractures which are unstable by their shape itself i.e. oblique fractures with very minimal communition. Type 2-Unstable fracture: There are further sub classified as (i) wedge fracture as in figure 38 (ii) oblique fracture as shown in figure 39. These fractures we designate as type 2.

Type 3 graph. Figure 40 and 41 show the current versus days graph for the three patients (1,4,5) with fractures with bone loss comminuted (broken into pieces) with gap and are also unstable involving the middle and lower third tibiae . Two cases (four and five) needed corticotomy and one case had accordion maneuver to induce healing .There were sharp spikes in the entire period till the stabilization of the current i.e. till the bone ends docked together and united. In this type of fractures it took longer time to stabilize. But for the same patients these spikes were less with their corticotomy sites recording perhaps due to the surgeon-made regular transverse bone cut. These fractures that had an irregular fracture line with gap is shown in figure 42 and with gaps ranging from 5mm to 5cm is designated as *Type 3.*

Summary

In stages of early fracture healing**,** in the current versus days graph, there was irregularity which stabilized later in the rest of the healing period. The types of the graphs

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differed with shape of the fracture and stage of healing, with irregularity increasing when fracture ends had unstable fracture configuration.

Figure 1.A patient who underwent exteral fixation , undergoes diagnostic electric stimulation .

Figure 2

Figure 3.

Figure 4

Figure 2 Pre-operative X-rays showing the patient with external fixator in first X-ray.

Figure .3,4. The next two X-rays are taken after the necrectomy (removal of the dead bone).

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Figure 5 and 6 Post operative X-ray after the Ilizarov ring application and corticotomy is marked with arrows.

8th day (680mA) 18th day (600mA) 28th day (670mA)

Figure 7

45th day (12.11.08) (700mA) 70th day (09.12.08) (710mA) 85th day (24.12.08) (640mA)

Figure 10 Figure 11 Figure 12

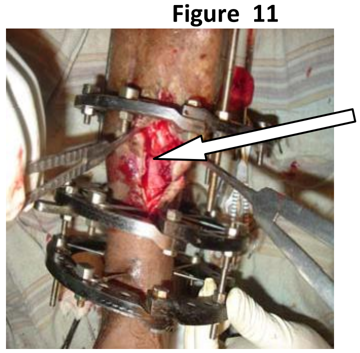

Fig 12. Open alignment of the bone fragments at the fracture site.

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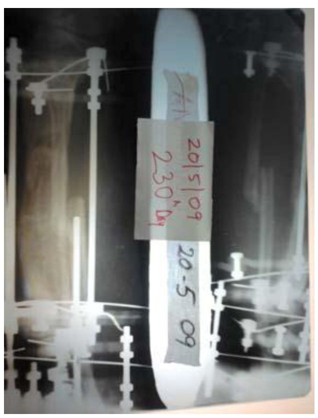
97th da y (05.01.09) (520mA)
Figure 13

120th day (29.01.09) (760mA)
Figure 14

148th day (24.02.09) (700mA)
Figure 15

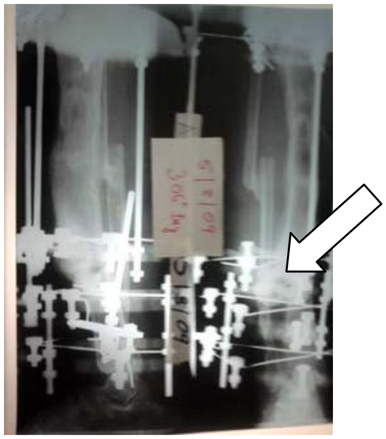


175th day (25.03.09) (700mA)
Figure 17

230th day (20.05.09) (630mA)
Figure 18

264th day (24.06.09) (40mA)
Figure 19

292nd day (22.07.09) (30mA)
Figure 20



306 th day (05.08.09) (30mA)

Figure 21

355 th day (23.09.09) (30mA)

Figure 22

Patient loading with the ring

Figure 23

Figure 24 X-rays taken after removal of ring, arrows showing the callus

Figure 25 After treatment and removal of ring, the patient is able to stand loading on the injured leg

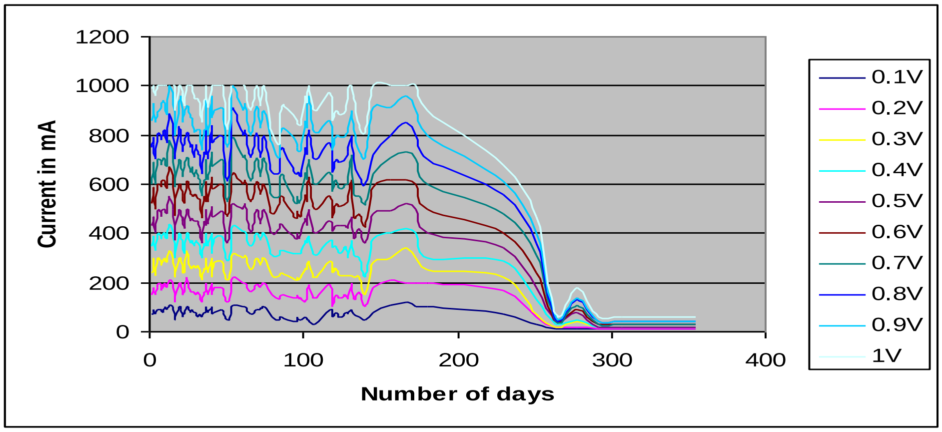


Figure 26. The variation in current as healing proceeds for 0.7 V D.C input.

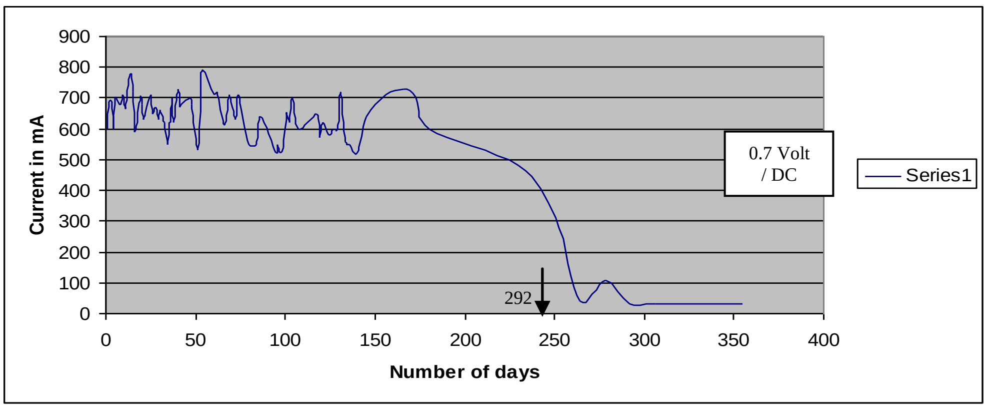


Figure 27. Current variation with time for case 4. across Corticotomy.

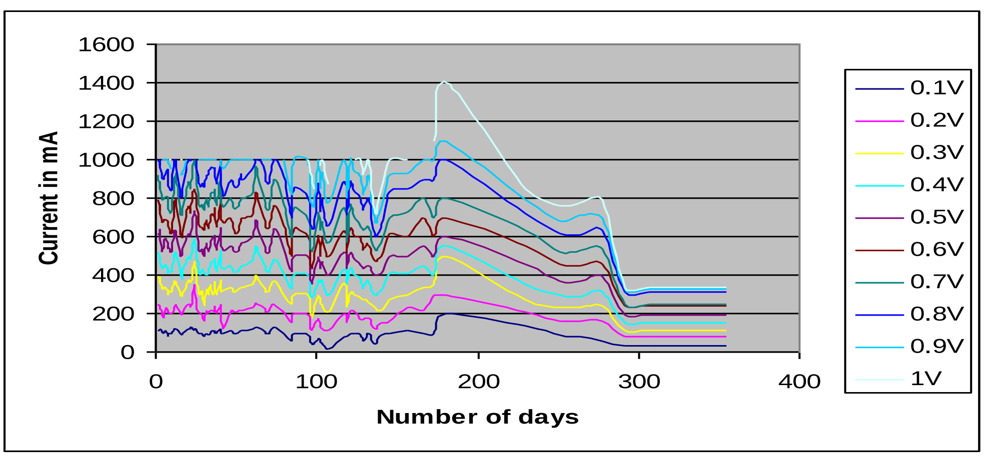


Figure 28. Current variation with time for case 4 across Fracture.

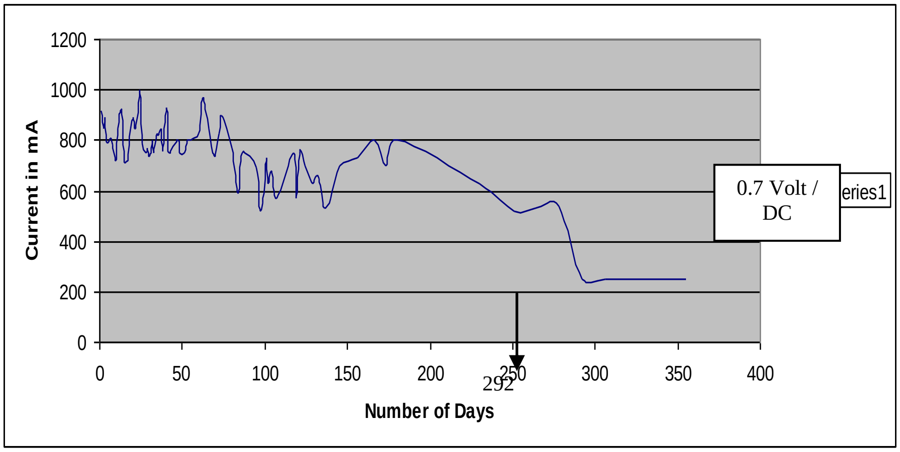
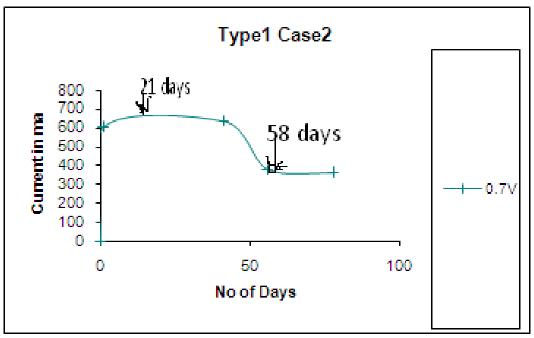


Figure 29. Current variation with time for case 4. (across fracture-site).



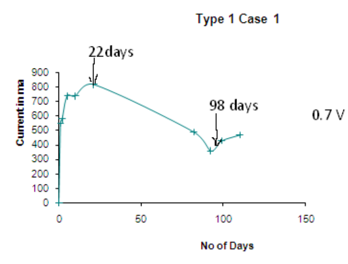


Figure 30 **Figure 31**

Figures 30 and 31 are the first type one graph pattern of the cases which had stable fracture configuration as seen in figures 32,33 and 34.as shown next.

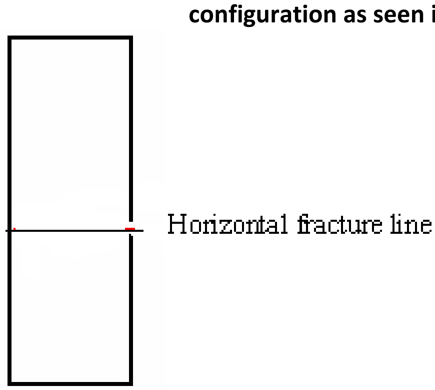


Figure 32. A stable horizontal fracture

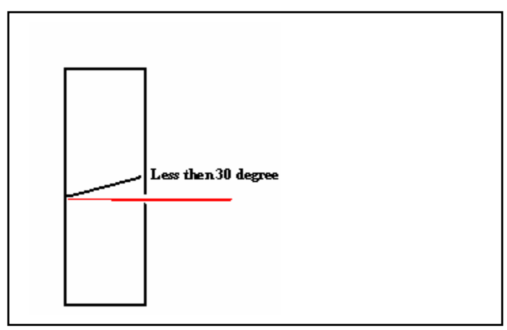


Figure 33 A stable inclined fracture

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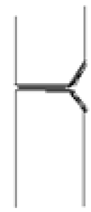
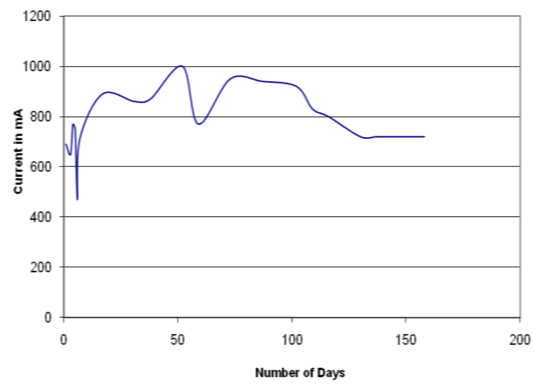


Figure 34 A stable fracture with minimal comminution



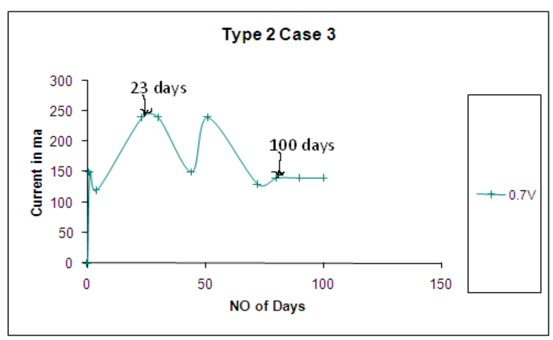


Figure 35 Figure 36

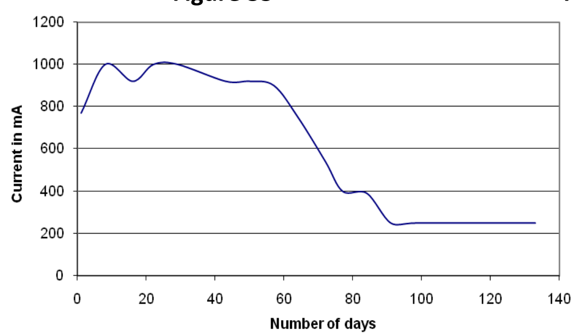


Figure 37

Figures 35,36 and 37 are the second graph pattern of the cases which had certain degree of instability in fracture configuration as seen in figures 38 and 39.as shown next.

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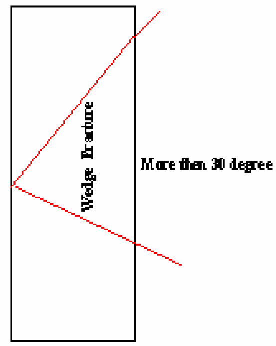


Figure 38. Wedge fracture with obliquity

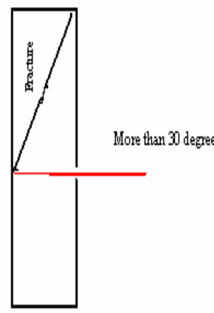
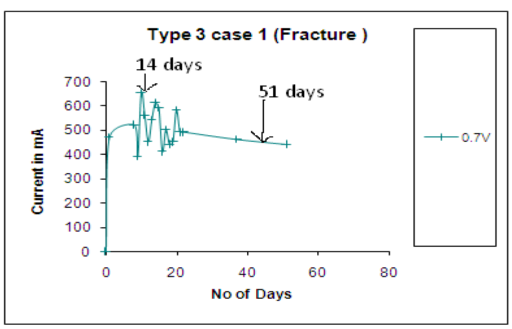


Figure 39. Oblique fracture



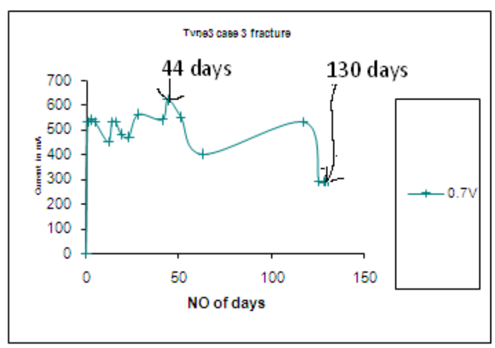


Figure 40

Figure 41

Figures 40 and 41 are the third graph pattern of the cases which had gap and instabilty in fracture configuration as seen in figures 42 as shown next.

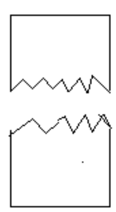


Figure 42. Irregular fracture with gap

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